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FURNEAUX'S HUMAN PHYSIOLOGY

NEW EDITION
COMPLETELY REVISED

BY
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PREFACE

SINCE the last revision of this book, great advances have been made in our knowledge of Physiology. In consequence, large portions of the book have been re-written, new chapters added (on Metabolism and the Endocrines), while the chapter on Histology has been considerably extended.

Some attempt has been made to present the subject matter from the standpoint of general physiology. My own experience of medical students is that they are too apt to think in terms of human physiology only, thereby missing the broader significance of the many phenomena with which they are constantly faced. For this reason the consideration of the evolutionary, comparative, and philosophical aspects of the subject is encouraged in the present book. A large number of the diagrams has been replaced by more up-to-date ones, and many new figures incorporated.

My cordial thanks are due to Mr. J. T. Cunningham, M.A., for his interest and advice. I am also deeply indebted to Miss Henrietta Wolff for help with the diagrams and index, and for much valuable criticism.

Various questions from the Second M.B. Examinations of the University of London have been added. My acknowledgments are due to the authorities concerned for their kind permission to reprint the questions.

W. A. M. SMART.

LONDON HOSPITAL MEDICAL COLLEGE.

March 20th, 1935.

PUBLISHERS' NOTE

THIS book is not only a popular text-book in the schools, it is also extensively used by nurses in training.

An alternative edition, *Nurses' Edition*, has therefore been published containing further matter required by such students.

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HUMAN PHYSIOLOGY

CHAPTER I

THE GENERAL BUILD OF THE HUMAN BODY

THE word **physiology** is derived from the two Greek words *phusis*, nature ; and *logos*, a discourse. Literally speaking, therefore, the subject embraces all the various branches of natural science. The term physiology is now generally applied only to the study of the functions of living beings.

Animal physiology deals with the functions of animals, while the term **human physiology** is of course restricted to the study of man ; and accordingly the object of this work is to give a brief and simple outline of the life-processes of the normal healthy human body.

It is impossible to understand the functions or uses of the various parts of the body without a knowledge of their structure. One, therefore, begins with a dissection of the dead body. This is a branch of science called **anatomy** (Gr. *ana*, up, and *temno*, I cut), and must go hand in hand with physiology.

Man belongs to that division of the animal kingdom known as **vertebrates** (Lat. *vertebra*, a turning joint) ; that is, he is characterised by the possession of a long dorsal chain of movable bones—the vertebral column. This kingdom comprises the fishes, amphibians, reptiles, birds and mammals. Man belongs to the class of **mammals**, whose characteristic is that of having breasts for suckling their young (Lat. *mamma*, the breast).

The most obvious division of the **human body** is into **head**, **trunk**, and **limbs** or **extremities**.

The **head** includes the **face**, and a bony box called the **cranium** which encloses the brain.

The **trunk** encloses a large cavity which contains the parts that are engaged in the circulation of the blood, respiration, digestion, etc. The upper portion of the trunk is called the **thorax** or **chest**, and the lower portion the **abdomen** or **belly**. These two parts are separated by a muscular partition called the **diaphragm** ; hence we speak of the cavity of the 'chest' as distinct from the cavity of the abdomen.

The **limbs** are arranged in two pairs—the **arms**, or upper extremities, and the **legs**, or lower extremities.

The body is made up of a large number of parts, each of which has its own particular function to perform. These parts are called **organs**. Thus, we speak of the *heart* as the chief organ of *circulation*, the *stomach* as an organ of *digestion*, the *lungs* as organs of *respiration*, and the *muscles* as organs for producing *motion*.

The various organs of the body may be conveniently arranged in groups or **systems**, according to their respective functions.

1. **The osseous, or bony system.**
2. **The muscular or contractile system.**
3. **The digestive and absorptive system.**
4. **The circulatory or transport system.**
5. **The respiratory, or breathing system.**
6. **The excretory, or purifying system.**
7. **The nervous or co-ordinating system.**
8. **The endocrine or internally secreting system.**
9. **The genital or reproductive system.**

All the organs of the body are more or less complicated in structure. Each one is built up of elementary structures which are called **tissues**. For example, the heart is mainly composed of a fleshy material which is termed *muscular tissue*, some fatty substance or *adipose tissue*, *nervous tissue*, and a certain amount of *connective tissue*.

1. **THE OSSEOUS SYSTEM** (Lat. *os*, a bone) consists of a large number of bones, which constitute the **skeleton**, and form a strong framework, which supports and protects the softer structures of the body. These bones are connected together in such a manner as to form **joints** or **articulations** (Lat. *articulus*, a joint), and are bound firmly together at these joints by strong white fibrous bands called **ligaments** (Lat. *ligo*, I bind). It is by means of these joints that movements of various sorts are made possible. In some parts of the body, where an elastic and yielding substance is required, which is at the same time very strong, **cartilage** or **gristle** takes the place of bone, as in the more prominent and flexible part of the nose. Bones also serve to protect underlying structures. The bony thorax protects the heart and lungs, the cranial bones protect the brain, while the pelvis protects the bladder, rectum and some of the female genital organs.

We may regard the **backbone** as the central portion of the

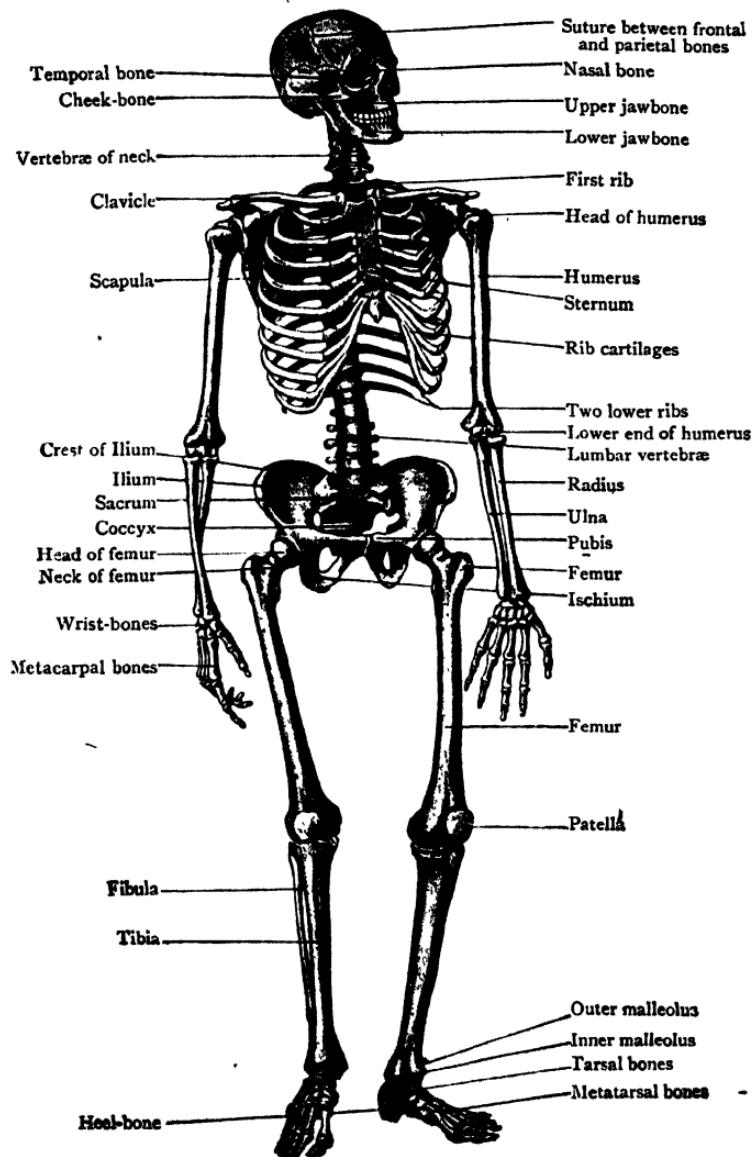


Fig. 1.—The Human Skeleton.

osseous system, for a glance at the accompanying figure will show that the other bones of the skeleton are connected either directly or indirectly with it. This bone (or, rather, column of bones) passes through the hinder part of the trunk of the body, part of it belonging to the neck, part to the back, and part to the loins. The ribs are connected with that portion which lies in the back, and, extending round the chest, are for the most part connected with the **breast-bone** in front. At the upper part of the chest are the **shoulder-bones**: to these the bones of the arms are attached. The lower portion of the backbone is wedged in between the **bones of the hip**, which form a hollow basin-like cavity, and support the organs of the abdomen and those of the pelvis.

The **skull** rests on the upper extremity of the backbone. It consists in part of a large, hollow, bony case. Continuous with the cavity thus formed is a tube which runs through the backbone. Hence it is common to speak of the human body as enclosing two distinct tubes or cavities: one surrounded by the skull and the backbone, and the other the great cavity already mentioned on page 1. The cavity formed by the backbone contains the spinal cord, while that formed by the skull contains the brain. This is true of all *back-boned* or *vertebrate* animals. Hence, some prefer the name *Craniata*, for they regard the skull as more characteristic.

The **arms** and the **legs** resemble each other very closely in the general arrangement of their bones. The scapula and clavicle correspond to the pelvic bones of the same side. The *upper arm* consists of one bone, which corresponds with the bone of the *thigh*. The *forearm* consists of two bones arranged side by side, as does also the leg. The bones of the wrist and hand, too, much resemble those of the ankle and foot respectively.

2. **THE MUSCULAR SYSTEM.**—The bones of the skeleton are all surrounded by more or less *flesh* or *muscle*. Each muscle is composed of bundles of fibres. These *fibres* have the power of contracting in the direction of their length and so shortening the muscles; and thus the bones with which the ends of the muscles are connected are brought nearer together. It is by this means that we are enabled to exercise the body in various ways. The muscles, too, assist very largely in giving a rounded form to the body.

Muscles are of three kinds—*voluntary*, *involuntary* and *cardiac*. The former are under the control of the will, while the

two latter are not. We have examples of voluntary muscles in those of the face and the limbs. The muscles of the stomach

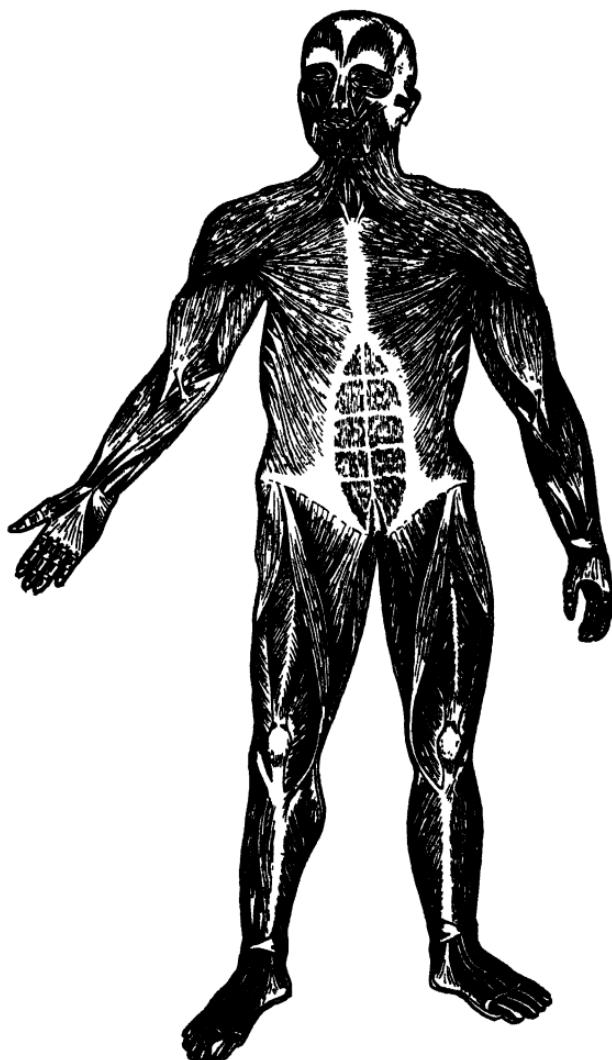


Fig. 2.—The Superficial Muscles of the Body (anterior view).

are of the involuntary kind, while those of the heart are of an intermediate nature, in some respects.

Those voluntary muscles which move the bones are connected with them by strong white fibrous bands called **tendons** (fig. 4).

3. THE ALIMENTARY SYSTEM IS DIGESTIVE AND ABSORPTIVE (Lat. *alimentum*, nourishment) and consists of the *food-passage* and the various organs which prepare

the *digestive fluids*. The **food-passage** consists of the *mouth*, *pharynx*, *œsophagus* or *gullet*, *stomach*, *small* and *large intestines*.

The **pharynx** (Gr. *pharunx*, the throat) is the cavity situated behind the mouth, with which it is continuous.

The **œsophagus** (Gr. *oisophagos*, gullet) is a tube, about ten inches long, connecting the pharynx with the **stomach**—a large pouch-like organ, which serves to contain the food while certain fluids are acting upon it.

After the food leaves the stomach, it passes through about 25 feet of muscular tubing called the **intestines**, which consist of the **small intestine** (about twenty feet in length), and the **large intestine** (about five feet).

In the small intestine the food is still further digested, i.e. reduced to a condition in which it can

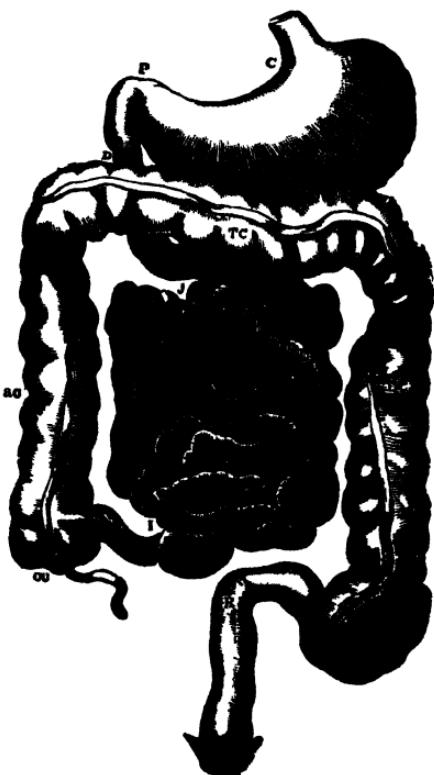
serves mainly as a storage

Fig. 3.—The Abdominal Portion of the Alimentary Canal.

c, cardiac opening of the stomach ; p, pylorus ; d, duodenum ; j, jejunum ; i, ileum ; cc, cæcum ; ac, ascending colon ; tc, transverse colon ; dc, descending colon ; r, rectum.

be absorbed. The large intestine of faeces for evacuation at intervals. It absorbs water, but no nutritive material.

4. THE CIRCULATORY OR TRANSPORT SYSTEM consists of the heart, blood-vessels and lymphatics.



The **heart** is a hollow, muscular organ, provided with valves, the whole serving as a force-pump to distribute the blood to all parts of the body. The **blood-vessels** consist of *arteries*

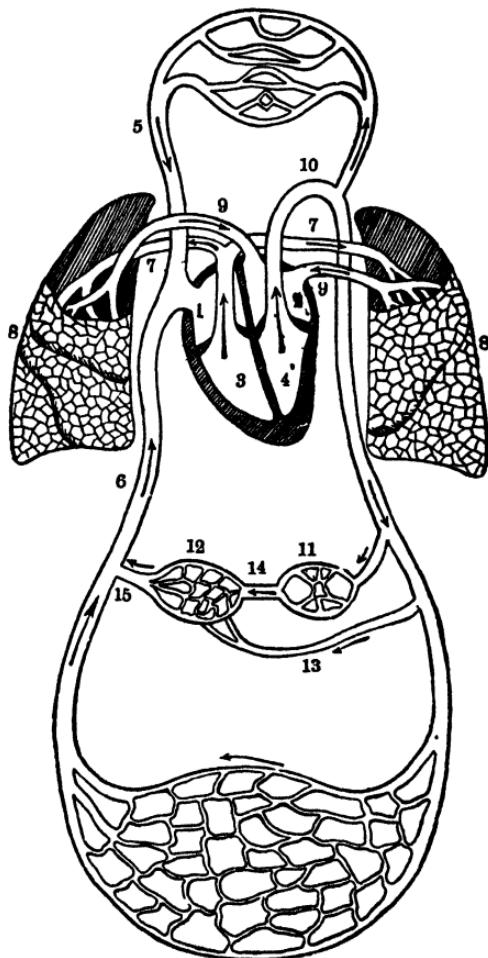


Fig. 4.—Diagram illustrating the Circulation.

1, right auricle; 2, left auricle; 3, right ventricle; 4, left ventricle; 5, vena cava superior; 6, vena cava inferior; 7, pulmonary arteries; 8, lungs; 9, pulmonary veins; 10, aorta; 11, alimentary canal; 12, liver; 13, hepatic artery; 14, portal vein; 15, hepatic vein.

capillaries and *veins*. The **arteries** convey blood *from* the heart; and they divide and subdivide into smaller and smaller branches, till at last they form very minute vessels called

capillaries. These capillaries, after a very short course, unite, forming small **veins**; and by the junction of these, larger and larger vessels are formed, which at length discharge their contents into the heart. Veins, therefore, are vessels which bring blood *to* the heart; and capillaries are the minute blood-vessels which connect the small arteries and veins together.

Some of the liquid part (plasma) of the blood exudes through

the thin capillary walls and bathes the surrounding tissues. This fluid is known as the **lymph**, which acts as an **intermediary** between the blood and the tissues. In like manner to the blood-vessels, there is a system of capillaries and veins, the **lymphatics**, which gather up the lymph and eventually discharge it into the blood-stream.

5. **THE RESPIRATORY SYSTEM** consists of the nose, **larynx**, **trachea** or **wind-pipe**, and the **lungs**. The **larynx**, sometimes called the voice-box, for it contains the "**vocal cords**" or membranes by

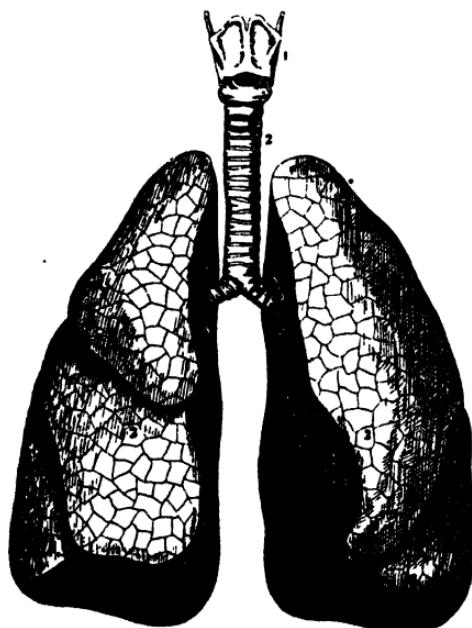


Fig. 5.—Front View of the Larynx, Trachea and Lungs.

1, larynx ; 2, trachea ; 3, lungs.

means of which the voice is produced, is the enlarged upper part of the passage leading from the mouth to the lungs. The **trachea** is a tube extending from the larynx to the upper part of the chest. Here it divides into two branches, one of which enters each lung. The **lungs** (popularly called the *lights*) are large spongy organs. They contain a very large number of small air cavities, and are richly supplied with blood-vessels. It is in the capillaries of the lungs that the blood is aerated by being brought into contact with the inspired oxygen. At the same time an important waste material, carbon dioxide,

is given up to the air in the lungs, from the blood circulating in its capillaries. Thus the respiratory system takes in oxygen and simultaneously gets rid of carbon dioxide.

6. THE EXCRETORY SYSTEM removes waste products from the blood. This is carried out by several organs, each concerned with the elimination of certain constituents.

The chief of these organs are the *liver*, the *kidneys* and the *skin*, to which may also be added the *lungs*; for, in addition to being aerated, the blood, while in the lungs, gives up carbon dioxide, which it has collected in its passage through the various parts of the body.

The **liver** is a very large reddish-brown organ, which prepares (among other things) a substance called **bile** from the blood. The bile is of very mixed composition, some constituents being utilised in the digestion of food; while others, such as **urea**, **bile pigments** and **uric acid**, are true waste products. The liver, therefore, is not simply an excretory organ, but also belongs to the digestive system.

The **kidneys**, two in number, are important blood-purifiers. Their function is to maintain the composition of the blood constant, by the excretion of waste material such as urea, uric acid, and the removal of certain other normal constituents if present above a certain percentage level, mostly salines.

The **skin**, which entirely covers the external surface of the

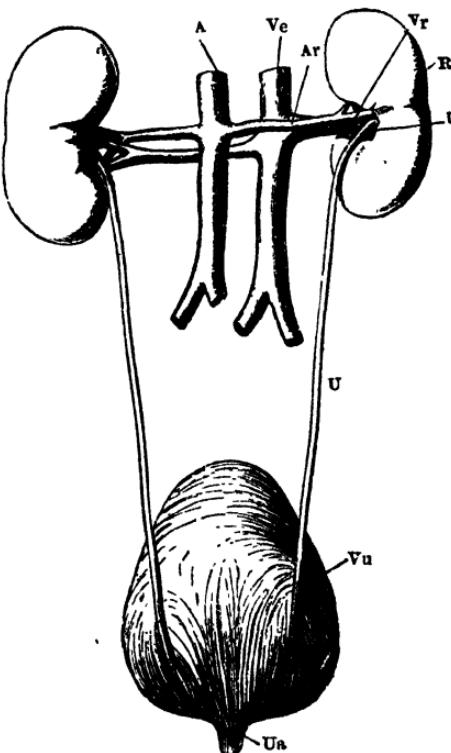


Fig. 6.—The Kidneys, Bladder, and their Vessels. Viewed from behind.

R, right kidney; U, ureter; A, aorta; Ar, right renal artery; Ve, vena cava inferior; Vr, right renal vein; Vu, bladder; Us, commencement of urethra.

body, is more than a mere protective covering, for its deeper layers contain numerous small bodies known as glands, in which a process of excretion is carried on. One set of these cutaneous glands produces the sweat which is conducted by minute tubes to the **pores** or openings which may be seen with a lens on the surface of the skin. Sweat is, however, only secondarily a source of loss—water and a trace of salts. This water is only lost, since by its evaporation a raised body temperature can be lowered to its normal level.

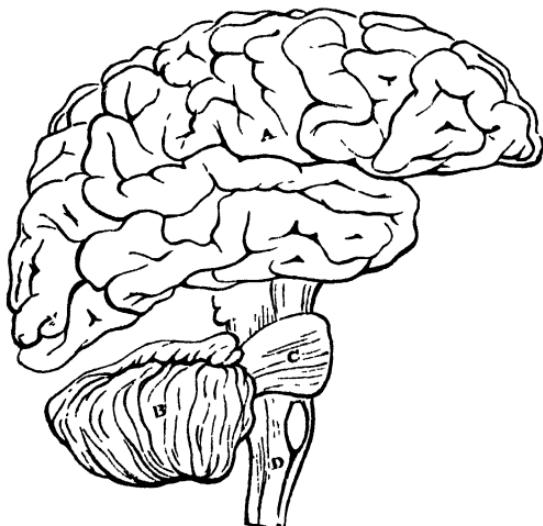


Fig. 7.—The Human Brain.

A, cerebrum ; B, cerebellum ; C, pons Varolii ; D, medulla oblongata.
The parts are represented as separated from one another somewhat
more than is natural so as to show their relation better.

7. THE NERVOUS OR CO-ORDINATING SYSTEM
consists of the brain, spinal cord, and the ganglia and nerves which connect them to the muscles, glands and organs of special sense. This system co-ordinates the various parts of the body, regulates their internal mechanisms, and adapts the body generally to its environment. By its means we receive impressions from the external world through the sense organs, viz. touch, pain, heat, cold, sight, taste and hearing. We also receive information concerning the position of the body in space, the condition of our muscles, and certain impressions with regard to the visceral organs—bladder, gut, stomach, etc.

In brief, the nervous system by its connection with the muscles causes and controls the motions of the body; by its connection with the glands and muscles of the alimentary system it regulates digestion, and by its connection with the sense organs we become aware of our external surroundings.

8. THE ENDOCRINE OR INTERNALLY SECRETING SYSTEM is made up of a set of organs (like the thyroid, thymus, suprarenals, pituitary and parathyroids) which secrete a chemical substance each peculiar to itself, but meant for action on some other organ. These glands have no ducts, and their secretory products are known as **autacoids** or, more commonly, **hormones** (Gr. *stimulating agents*), though they are not all stimulant. The hormones are passed directly into the lymph or blood-stream, and eventually reach all parts of the body, but they only affect each its own particular structure—stimulation or depression, as the case may be.

The endocrine glands form an interrelated system which regulates body-growth and development, its metabolic rate, and also affects the activity of the autonomic nervous system—a special branch of the general nervous system. This chemical control of bodily functions is additional to that exerted by the nervous system.

SUMMARY

THE VARIOUS SYSTEMS OF THE HUMAN BODY

1. **OSSEOUS SYSTEM**—movement framework for support, protection.
Bones of the skull, pelvis, limbs.
Vertebral column, ribs, breast, and collar-bones.
2. **MUSCULAR SYSTEM**—movement of limbs, body or organs.
Skeletal muscle—voluntary, rapid action.
Cardiac muscle }
Plain muscle } involuntary, rhythmic, slow action.
3. **ALIMENTARY SYSTEM**—digestion, absorption, metabolism.
Mouth, teeth, tongue, oesophagus.
Stomach, small and large intestines.
Glands—salivary, gastric, intestinal, pancreas, liver.
4. **CIRCULATORY SYSTEM**—transport of nutrient, heat, waste.
Heart, arteries, capillaries, veins.
Blood, lymph, lymph-vessels and nodes (glands).
5. **RESPIRATORY SYSTEM**—intake of O₂, output of CO₂.
Nose (and mouth), pharynx, larynx.
Trachea, bronchi, lungs—bronchioles, alveoli.
6. **EXCRETORY SYSTEM**—output of waste material.
Liver (bile), lungs (water vapour, CO₂), kidneys (water, salts),
skin (water, salts).

7. **NERVOUS SYSTEM**--co-ordination of all bodily functions.
Brain, spinal cord, ganglia. Nerve cells, dendrites and axons.
8. **ENDOCRINE SYSTEM**--production of autacoids (hormones) for activity of other organs—stimulation or depression.
Thyroid, parathyroids, thymus, gonads, islets of pancreas, suprarenals, pituitary (anterior and posterior).

CHAPTER II

THE OSSEOUS SYSTEM—SPINAL COLUMN AND RIBS

GENERAL SCHEME.—We begin with a general view of the skeleton and its arrangement. For this purpose imagine we are looking at a vertebrate animal lying face downwards. A line from its snout to its tail divides the body into two symmetrical halves. This line is the *principal axis* and represents the backbone or vertebral column. At the front or anterior end (upper in the case of man) is the bony skull. Next come two *secondary axes* at right angles to the principal one, giving the positions of the limbs in the primitive condition. These limbs are fixed to and surround the body by a set of bones forming a sort of girdle. At the anterior or front end we have the **pectoral** girdle to which the arms or fore-limbs are fixed. Similarly at the posterior or lower end we have the **pelvic** girdle to which the hind limbs or legs are attached.

This is the general plan of the original skeleton of the air-breathing vertebrates. It should, however, be borne in mind that the different classes of vertebrates depart greatly from this plan each in their own way. This depends on their very varied habits, leaping, burrowing, climbing, running, etc., but in all cases the above general scheme can be made out. Our interest here is concerned with mammals, and, in particular, the *human* body; and, unless otherwise stated,

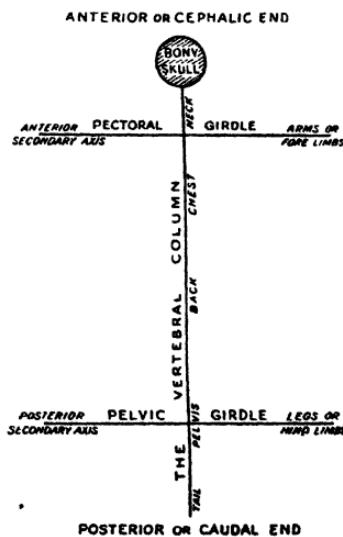


Fig. 8.—General Scheme of the Vertebrate Skeleton.

the illustrations all refer to man. Nevertheless, it must be remembered that the structure of the human body is in all its broadest features similar to that of many of the lower animals ; so much so, that a description of the human body may be illustrated by the dissection of one of these animals. It is very desirable, therefore, that even beginners in the study of human physiology should examine the bodies or parts of such animals as can be conveniently procured. Thus, a knowledge of the position and uses of the various parts of the skeleton may be obtained by a thoughtful inspection of the bones of a rabbit ; or the student may easily prepare for himself a complete skeleton of any small animal by burying the body just beneath the surface of a wet soil. In a few weeks the flesh will have decomposed to such an extent that the skeleton may be washed clean in running water, and afterwards bleached by exposure to the sun.

There are 206 distinct bones in the adult skeleton, made up as follows :—22 in the skull, 26 in the vertebral column, 1 hyoid bone, 24 ribs, 1 sternum, 64 in the upper limbs, 62 in the lower limbs, and 3 in each ear.

We shall first study the backbone, or central portion of the skeleton (*Gr. skello*, I dry up), and the bones directly connected with it.

THE VERTEBRAL OR SPINAL COLUMN is composed of a series of bones called *vertebræ* (*Lat. verto*, I turn), and forms the axis with which all the other parts of the skeleton are connected. The base of the skull rests on the uppermost of these *vertebræ*, and the lower portion of the column is wedged in between the bones of the hip. The backbone is usually said to consist of thirty-three bones, but only twenty-four of these are jointed in such a manner as to be movable on each other, viz. the bones of the neck, back, and loins. They are known as the *true* or movable *vertebræ*. The lower part of the column consists of nine bones fused together, and known as *false* or *fixed vertebræ*. The seven highest *vertebræ* belong to the neck, and are called the **cervical vertebræ** (*Lat. cervix*, the neck). The next twelve are called the **dorsal or thoracic vertebræ** (*Lat. dorsum*, the back) ; these belong to the back and support the ribs. The remaining five movable *vertebræ* belong to the loins, and are called the **lumbar** (*Lat. lumbus*, the loin) *vertebræ*.

The lowest lumbar *vertebra* rests on the broad upper surface of a curved wedge, formed by the next five *vertebræ* fused

together into one firm mass of bone, which has to bear the weight of the whole of the body lying above it. This wedge is called the **sacrum** (Lat. *sacred*), and to its lowest and narrowest end is attached the **coccyx** (Lat. a *cuckoo*), which consists of four very imperfectly formed vertebrae, corresponding morphologically with the tail in other animals. In the rabbit, for instance, there are about fifteen vertebrae in the tail, the coccyx being replaced by the **cauda** (Lat. *tail*).

The sides of the sacrum are united with the two large **hipbones**, and form a basin-like cavity called the **pelvis** (Lat. a *basin*). These will be more conveniently described with the bones of the limbs.

In order to understand clearly the construction and uses of the vertebral column it will be necessary to notice the form of a single vertebra; and though the vertebrae differ from each other in detail, yet all are constructed on much the same plan, and a general description of one will answer for all.

A **vertebra** consists of a roughly circular solid bony *body* from which spring two *neural arches*, the latter uniting in such a manner as to form a bony

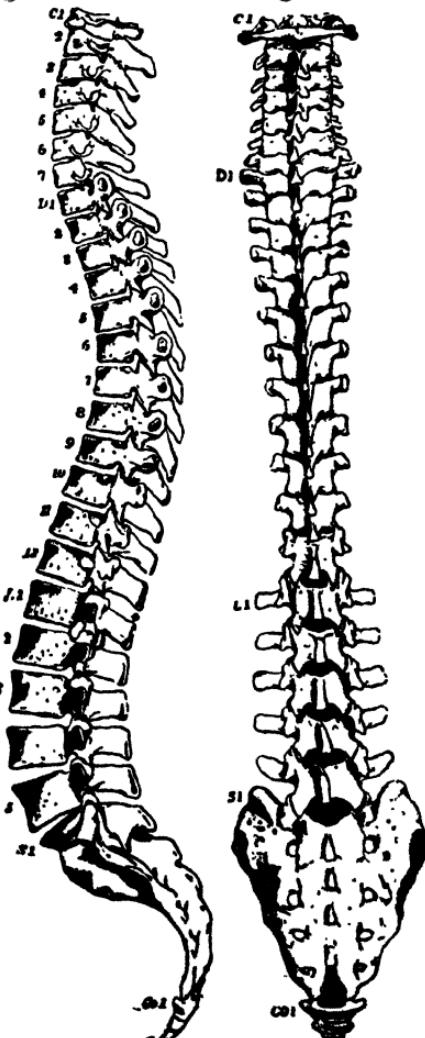


Fig. 9.—The Vertebral Column, viewed from the left side.

C₁, first cervical vertebra; D₁, first dorsal vertebra; L₁, first lumbar vertebra; S₁, first sacral vertebra; Co₁, first coccygeal vertebra.

Fig. 10.—The Vertebral Column, viewed from behind.

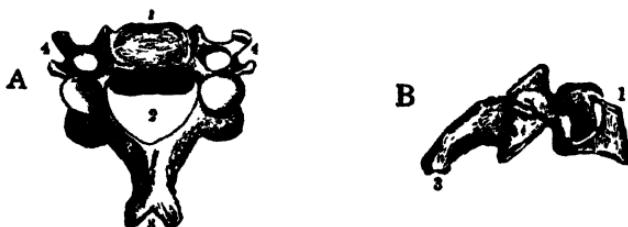


Fig. 11.—A Cervical Vertebra (3rd).

A, viewed from above ; B, viewed from the right side.
1, spinal cavity ; 2, body ; 3, spinous process ; 4, lateral processes.

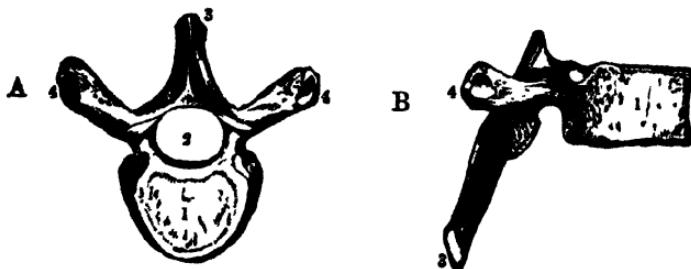


Fig. 12.—A Dorsal Vertebra (6th).

A, viewed from above ; B, viewed from the right side.
Numbers as in fig. 11.

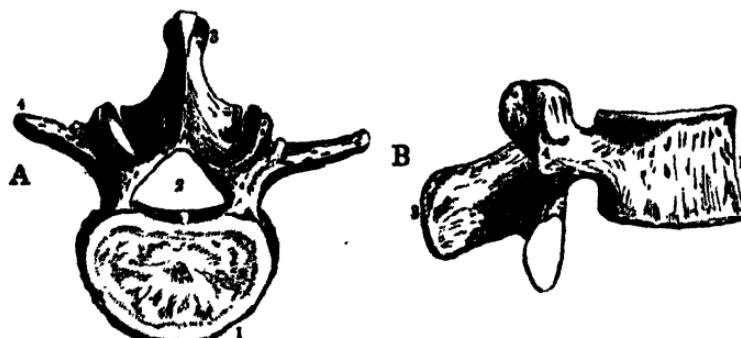


Fig. 13.—A Lumbar Vertebra (3rd).

A, viewed from above ; B, viewed from the right side. Numbers as in Fig. 11.

ring which encloses a space, the *spinal cavity*. From the outer circumference of this bony ring are given off three projections, which are called **processes**. The body is the front or anterior portion of the vertebra, and constitutes its main bulk. The process which projects from the arch, exactly opposite the body, is called the **spinous process**. Two other processes arise from the sides of the ring, and are called **lateral processes**. These projections from the vertebrae serve as places of attachment for the ligaments which hold the bones firmly together; and also for the muscles by which we are enabled to bend the back and to move those bones that articulate with the vertebral column.

Between the bodies of the vertebrae are pads of elastic cartilage or gristle called **intervertebral discs** or **cartilages**. These unite the vertebrae, and form with them a flexible column. They also serve to act as buffers, to prevent sudden jars to the spinal cord contained within them, and the vertebrae. In old age the cartilages of the backbone become hard and less flexible, so that the back can no longer be bent, except to a very slight extent; hence the possibility of fractures in the old, by comparatively slight causes.

The points in which these vertebrae differ from each other may receive a passing notice. The **bodies** of the vertebrae increase in size from the first cervical to the lowest lumbar, so as to be able to support the greater weight they have to bear. The bodies of the *cervical vertebrae* being small, we have seven joints in a short column of bones. This gives great freedom of motion to the head and neck. The first two cervical vertebrae will be specially described in our next chapter. The cervical vertebrae are characterised by holes, the *vertebrarterial canals* which appear to perforate their lateral or transverse processes. The vertebral artery of each side traverses these canals. The long spinous processes of the *dorsal vertebrae*, which show so

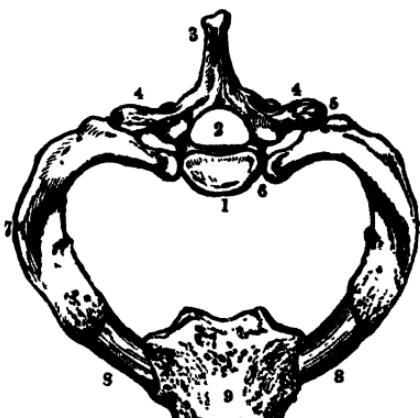


Fig. 14.—First Dorsal Vertebra, with the first pair of Ribs, and a portion of the Sternum.

1, body of the vertebra; 2, spinal cavity; 3, spinous process; 4, lateral processes; 5, articular facet of lateral process; 6, articular facet for the head of the rib (these two facets form, with the rib, movable joints); 7, ribs; 8, cartilage or gristle connecting the ribs with the sternum; 9, sternum (manubrium).

plainly in the backs of thin persons, and the large spinous and lateral processes of the lumbar vertebræ, serve for the attachment of the powerful muscles by which we are enabled to bend the body. The *dorsal vertebræ* are also provided each with two *facets*, sometimes called the *articular processes*, with which the heads of the ribs form movable joints.

It will now be seen that a number of these vertebræ, arranged in a column, will not only form a powerful and flexible support,

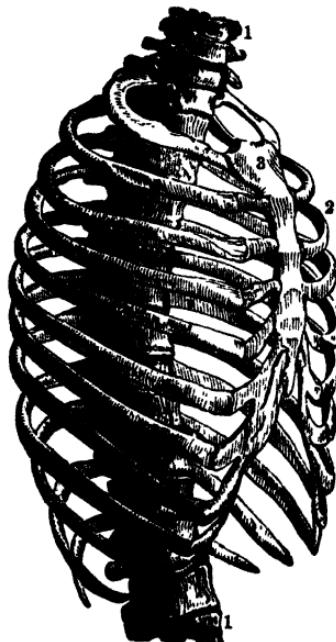


Fig. 15.—The Bony Framework of the Chest, viewed from the right side.

1, backbone; 2, ribs; 3, breast-bone.

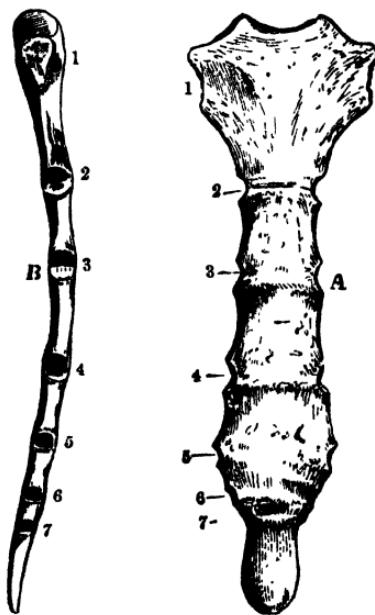


Fig. 16.—The Breast-bone.

A, viewed from before; B, viewed from the right side; 1, 2, 3, 4, 5, 6 and 7 are the surfaces to which the corresponding costal cartilages are attached.

but that the vertebral arches will form a long bony tube. This tube is called the **spinal canal**, and contains the **spinal cord**, to which the bones of the vertebral column serve as a strong protection. Note also that the column is flexuous—it has concavities and convexities. The cervical and lumbar regions are concave dorsally, while the thoracic and sacral regions are concave ventrally.

THE RIBS (*costæ*), twelve each side, are curved bones, connected in pairs with the dorsal vertebræ behind, and, except the last two pairs, with the **sternum** (Gr. *sternon*, the breast) or **breast-bone** in front. Each pair of ribs thus forms a circular elastic arch enclosing the thorax. That portion of the rib which forms a movable joint with the articular process of the dorsal vertebræ is termed its *head*. The other end is in most cases attached by means of **costal cartilage** to the **breast-bone** —a long, flat bone, the lower part of which is formed of flexible cartilage. It will thus be seen that the ribs, together with the backbone and the sternum, form an elastic framework with movable sides. This acts as a protection to the organs contained in the *chest* or upper portion of the trunk, and assists largely in the process of respiration.

The **ribs** are not placed horizontally, but incline *downwards* from the backbone, so that when they are raised and depressed, as they are during the inspiration and expiration of air in breathing, the capacity of the chest is alternately increased and decreased.

We may now notice the manner in which the pairs of ribs differ from each other. In the first place we observe that the upper pairs form small arches, and that the size of the arches increases from above downwards; thus the framework formed is somewhat conical. The *first seven pairs* have their own costal cartilages, connecting them directly with the sternum. They are called *true* or *vertebro-sternal ribs*. The *first* is the most curved, broadest, flattest and shortest. The *eighth, ninth, and tenth pairs* are each connected with the cartilage next above it, so that they are united to each other before they reach the sternum. They are thus called *vertebro-chondral ribs*. The *eleventh and twelfth pairs* are not connected at all with the breast-bone. The *last five pairs* are called **false ribs**; and of these the eleventh and twelfth pairs are termed **floating** or **vertebral ribs**, for their anterior ends are free. Occasionally a rib develops from the seventh cervical vertebra, and may necessitate a surgical operation.

The **collar-bone**, which is attached medially to the upper end of the sternum, and laterally to the **shoulder-blade** (which lies behind the upper ribs), will be best described with the bones of the arm.

SUMMARY

THE BONES OF THE TRUNK

VERTEBRAL COLUMN (33 bones originally)	7 Cervical—Neck . . .	{ Small bodies. Vertebrarterial canals. Processes { Spinous—short and bifid. Lateral—small. Give attachment to ribs.
	12 Thoracic—Back . . .	{ Larger bodies—heart-shaped. Processes { 1 Spinous—long. 2 Lateral—thick. 4 Articular—ribs with heads.
	5 Lumbar—Loins . . .	{ Very large bodies. Processes Spinous—thick and broad. Lateral—long and slender.
	Sacrum—5 (fused) . . .	{ United, forming a wedge. Fixed between hip-bones.
	Coccyx—4 (fused) . . .	Rudimentary and morphological with tail.
RIBS (12 each side)	7 Pairs true . . .	{ Connected by their own cartilages with the sternum—vertebro-sternal.
	5 Pairs false . . .	{ 8th, 9th, 10th pairs—each connected with the cartilage above it—vertebro-chondral. 11th and 12th pairs—free—fixed at vertebral end only, very short.

CHAPTER III

THE OSSEOUS SYSTEM—THE SKULL

THE SKULL.—The skull is the large bony case at the anterior or upper extremity of the vertebral column. It consists of the *cranium* and the *face*. The *cranium* is a large and hollow bony case which encloses the *brain*. The *face* forms the front and lower portion of the skull. The cranium is usually said to consist of eight bones and the face of fourteen ; but it must be understood that in early childhood some of these bones consist of parts which are quite distinct ; also that, in the adult, some of the bones originally distinct are fused together into one mass.

The bones of the cranium or brain-case are :

One occipital.	Two temporal.
Two parietal.	One sphenoid.
One frontal.	One ethmoid.

They are united by means of irregular saw-like edges or *sutures*, which firmly lock them together. The points of junction of three or more sutures are called *fontanelles*. Strictly speaking, there are six of them, but only two are of importance—the anterior and the posterior. The former is the larger. It is roughly lozenge-shaped, is always patent at birth, and takes about twenty months to close. The posterior fontanelle is of triangular shape, situated in the mid-line at the back of the skull, and is almost closed at birth. It lies at the junction of the parietals with the occipital, while the anterior fontanelle is formed by the sutures of the frontal and parietal bones, and is easily seen and felt in the head of a new-born baby. These fontanelles are only covered with a very thin skin, and can be easily damaged. They are of use in the diagnosis of the position of the foetal head at the commencement of labour.

The *occipital bone* (Lat. *ob*, against; and *caput*, head) forms the back and a part of the base of the skull. Its lower portion is perforated by a large circular opening, about an inch and a half in diameter, called the *foramen magnum* (Lat. *foramen*, a hole ; *magnus*, great), by which the brain cavity is made to communicate with the spinal canal. On each side of

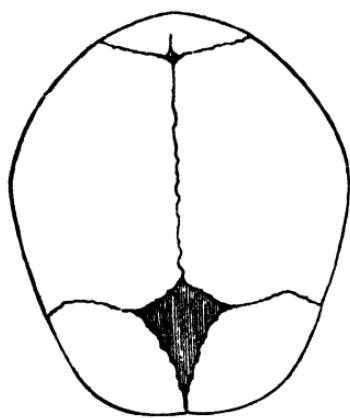


Fig. 17.—The Skull at Birth showing the Anterior and Posterior Fontanelles.

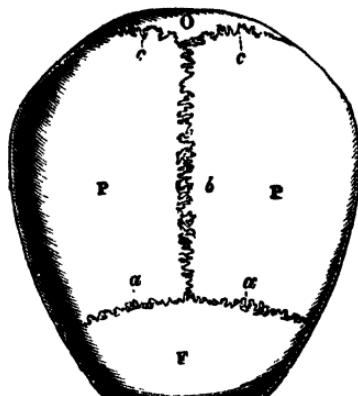


Fig. 18.—Superior view of Skull.
F, frontal bone; P, parietal bones; O, occipital bone; a, coronal suture, b, parietal suture; c, lambdoidal suture.



Fig. 19.—Lateral view of the Skull.

1, frontal bone; 2, parietal bone; 3 and 8, occipital bone; 4, wing of the sphenoid bone
5, 6 and 7, temporal bone; 10, lachrymal bone, in the inner wall of the orbit; 11, malar bone;
12, superior maxillary; 13, ramus; and 14, body of inferior maxillary, or mandible.

the front portion of this cavity is situated a rounded projecting mass of bone called the **condyle** (Gr. *kondulos*, a knuckle). These two condyles fit into two corresponding depressions in the first cervical vertebra, thus forming a pair of joints which permit of a rocking or nodding motion of the head.

The upper edge of the occipital bone is united with the **parietal bones** (Lat. *paries*, a wall), which form the side walls and the greater portion of the roof of the cranium. They are of quadrilateral shape.

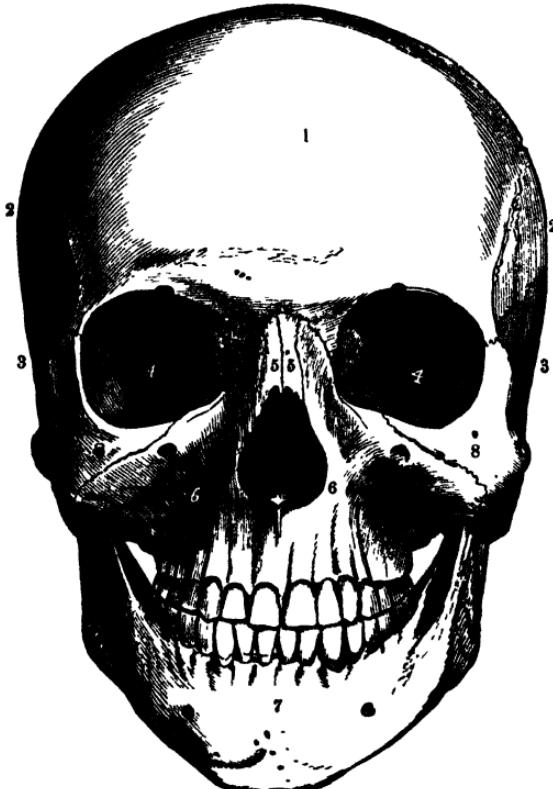


Fig. 20.—The Skull (anterior view).

1, frontal bone; 2, parietal bones; 3, temporal bones; 4, portions of the sphenoid bones, forming the backs of the orbits of the eyes; 5, nasal bones; 6, superior maxillary bones; 7, inferior maxillary bone; 8, malar or cheek-bones.

The **frontal bone** (Lat. *frons*, the forehead) forms the front of the cranium. It is united with the two parietals behind, and extends over the forehead, forming the roofs of the orbital and nasal cavities. The frontal bone in a baby is divided into two parts by a space which is continuous with the line of division between the parietal bones (the frontal suture).

The base of the skull, in front of the occipital bone, is formed by the **sphenoid bone** (Gr. *sphen*, a wedge; and *eidos*, form). It much resembles

a bat in shape with extended wings. It is wedged in between the other bones of the base of the skull, and extends forward to meet the frontal bone in the *orbita*. It articulates with twelve bones.

The **ethmoid bone** (Gr. *ethmos*, a sieve; *eidos*, form) fills the space between the orbits, and is so called because it is perforated by a large

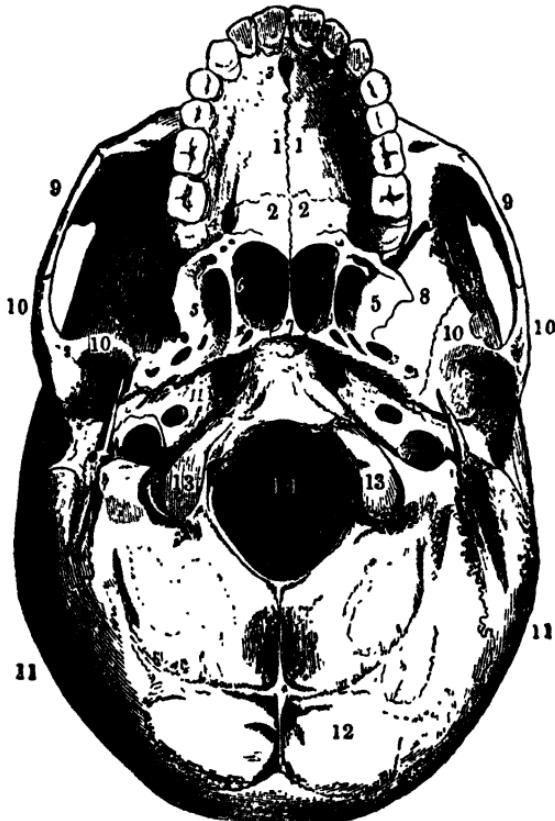


Fig. 21.—The Under or Inferior Surface of the Skull.

1, superior maxillary bones; 2, palatal bones; 3, anterior palatine foramen; 4, lesser palatine foramina; 5 and 8 are on the sphenoid bone; 6, hinder opening of the right nostril; 7, vomer; 9, malar or cheek-bones; 10, temporal bones; 11, lower portion of parietal bones; 12, occipital bone; 13, condyles of the occipital bone; 14, foramen magnum.

number of small openings, through which the branches of the nerve of smell pass from the nose to the brain. This bone is very irregular in form, and extends into the cavities of the nose.

The **temporal bones** (Lat. *tempus*, time) are so called because they are situated in those parts of the head (the temples) where the effects of time are first shown by the appearance of grey or white hairs. They are attached to

the sphenoid bone in front, the parietal bones above, and the occipital bone behind. They also send out processes which unite with the *cheek-bones*, forming bony arches. There is a special part of the temporal bone, known as the *petrous* portion, which contains within it the essential parts of the organs of hearing and of equilibrium.

The bones of the face are as follows :—

Two superior maxillary.	Two inferior turbinated.
Two palatal.	One vomer.
Two nasal.	Two malar or cheek-bones.
Two lachrymal.	One inferior maxillary or mandible.

The **superior maxillary bones** (Lat. *maxilla*, a jaw) form the upper jaw, and the greater portion of the **palate** or roof of the mouth. In them are fixed the upper set of teeth. Behind these bones are the two **palatal bones** (Lat. *palatum*, the roof of the mouth), which form the hinder portion of the palate.

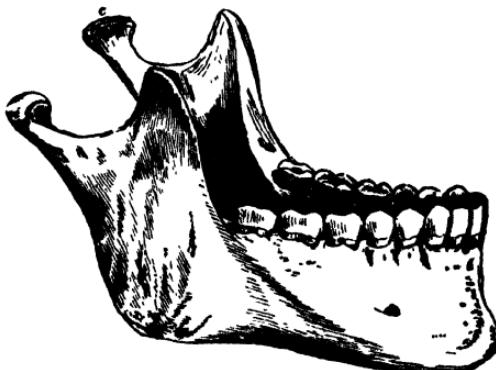


Fig. 22.—The Inferior Maxillary Bone, or Mandible.
c, the condyles, which articulate with the temporal bones.

The **nasal bones** (Lat. *nasus*, the nose) are two very small bones situated between the sockets of the eyes, and forming the upper and hard ridge of the nose. Very near these bones, separated from them by a narrow portion of the superior maxillaries, are the two small **lachrymal bones** (Lat. *lacryma*, a tear), the smallest and most fragile bones of the face. They are so called because they are grooved for the **nasal ducts** which convey the tears from the eyes into the cavities of the nose.

A large portion of the face is occupied by the two **nasal cavities** and the bones which form their walls. The **inferior turbinated bones** (Lat. *turbo*, a turning round) are spongy in texture, and curved round like scrolls, and project from the outer wall of the nasal cavities. These cavities are separated by a very thin vertical bone, the **vomer** (Lat. a ploughshare). It forms the hinder and lower part of the nasal septum.

The **malar or cheek-bones** (Lat. *mala*, the cheek) are the two most prominent bones of the cheeks. They unite with the superior maxillaries

in front, and send out processes behind which join with similar projections from the temporal bones, forming the arches which have already been mentioned. The cheek-bones also help to form the lateral wall and floor of the orbit.

The remaining bone of the face is the **inferior maxillary** or lower jaw. It is the largest bone in the face, and in it is fixed the lower set of teeth. It is the only movable bone of the skull. It gives off two processes which form joints with sockets in the temporal bones; and these joints are so constructed that the lower jaw has not only a vertical movement, but is capable also of motion sideways, backwards and forwards. It is a hinged and gliding joint (ginglymo-arthrodial).

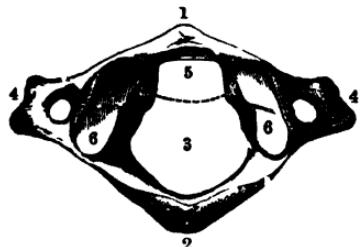


Fig. 23.—The **Atlas**, or First Cervical Vertebra, viewed from above.

1, the anterior arch; 2, the posterior arch; 3, spinal cavity; 4, lateral processes; 5, marks the position of the odontoid peg of the axis; 6, concave surfaces which articulate with the occipital bone. The dotted line marks the position of the ligament which secures the peg. The body is absent, but is represented by the odontoid peg of the axis.

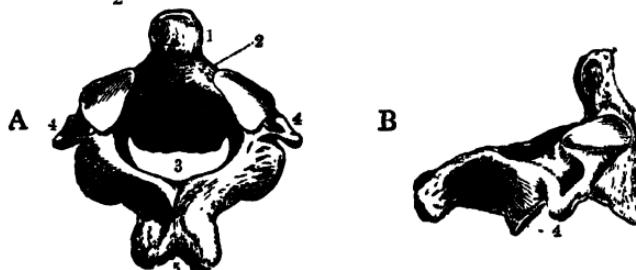


Fig. 24.—The **Axis**, or Second Cervical Vertebra.

A, viewed from above and behind; B, viewed from the right side; 1, odontoid process; 2, body; 3, spinal cavity; 4, lateral processes; 5, spinal process.

It will be observed that several bones enter into the formation of the **orbits** or **sockets of the eyes**. The roof of each orbit is formed by the frontal and sphenoid bones; the inner wall by the lachrymal bone, the superior maxillary, and the ethmoid; the floor by the superior maxillary and malar; and the outer wall by the malar and the great wing of the sphenoid. These orbits (*Lat. orbita*, a track in which a body turns) contain the eyeballs, the lachrymal sac and gland, the muscles which turn the eyeball, and a certain amount of fatty matter which acts as padding to protect the organ of vision.

We must now notice how the head turns on the vertebral column. It has already been seen that the skull rocks or nods on the vertebral axis by means of a pair of joints, formed by projections (*condyles*) of the occipital bone, and the corresponding depressions or sockets in the first cervical vertebra, the

atlas. But were these the only joints permitting a movement of the head, that motion would be restricted to nodding. We know, however, that the head turns freely to right and left. This is explained as follows. The *second cervical vertebra*, the **axis**, sends upward a tooth-like projection called the **odontoid process** (Gr. *odous*, tooth; and *eidos*, form). This peg forms an axis on which the atlas turns, and is kept in its position against the front inner surface of the atlas by means of a powerful ligament, known as the transverse ligament of the atlas. Thus, when the head turns to right or left, the skull and the atlas move together, both rotating on the process of the axis. It should be explained that the atlas has no body, thus allowing the odontoid process to pass up and occupy the space thus left. A "broken neck" is often a fracture of the odontoid process.

SUMMARY

SKULL (22 bones)	Cranium (8 bones)	1 Occipital —at back and base of skull; has a large opening, <i>foramen magnum</i> .
	Face (14 bones)	2 Parietal —the side walls and roof. 1 Frontal —the forehead bone. 2 Temporal —bones of the temples. 1 Sphenoid —irregular, bat-shaped. 1 Ethmoid —between orbits and nasal roof. 2 Superior maxillary —upper jaw, teeth. 2 Palatal —form back part of palate. 2 Nasal —form the bridge of the nose. 2 Lachrymal —on nasal side of orbits—form the nasal ducts and sacs. 2 Turbinated —scroll-shaped bones of nose. 1 Vomer —separates nasal cavities. 2 Malar —cheek-bones. 1 Inferior maxillary —the lower jaw—the only movable bone. Contains lower teeth Roof —sphenoid, frontal. Inner Wall —lachrymal, ethmoid, superior maxillary and sphenoid. Outer Wall —malar and sphenoid. Floor —superior maxillary, malar, palatal.
Bones forming the Orbita		

CHAPTER IV

THE OSSEOUS SYSTEM—GIRDLES AND LIMBS

GENERAL PLAN OF THE GIRDLES AND LIMBS.—

The limbs are attached to the skeleton by a group of bones nearly encircling the body, hence the name *girdle*. The arms are attached by the **pectoral girdle** (Lat. *pectus*, the breast), while the lower limbs are attached by the **pelvic girdle** (Lat. *pelvis*, a basin). Originally each consisted of three bones on each side, united together thus λ to form a socket into which is

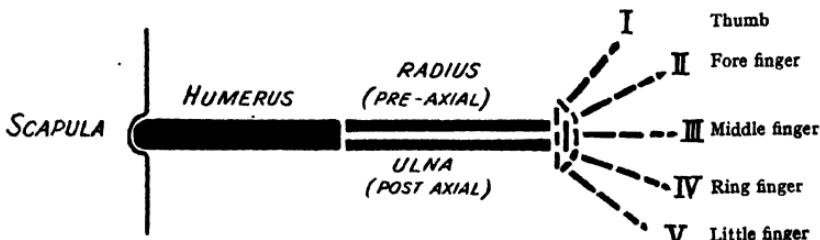


Fig. 25.—Diagram of a typical forelimb of a pentadactyle vertebrate. The limb is stretched out at right angles to the body axis, with the palms downwards (pronation).

fitted the articulating head of a limb. It is easier to identify these bones in the case of the pelvic than in the pectoral girdle.

The original arrangement of the limb girdles and limbs was in the form of secondary axes which stood out at right angles to the vertebral column or principal axis. The first bone of the secondary axis is a single long bone articulating with the cavity in the girdle. Next follow two parallel long bones which articulate with the lower end of the first-mentioned bone. One bone is in front of the axis, *preaxial*, while the other is behind, i.e. *postaxial*. At the outer end of these two parallel bones is a group of small bones arranged in three rows, of three, one, and five each respectively. Articulating with each member of the last row of these bones is a single bone, and finally, beyond this is a group of three (in general), forming the fingers or toes.

This is the primitive plan of the pentadactyle limb, but this has undergone considerable modifications, in man and the other air-breathing vertebrates.

THE PECTORAL GIRDLE AND UPPER LIMB
consist of the *shoulder*, the *upper arm*, the *forearm*, the *wrist*,
and the *hand*. The bones forming the above may be classified
as follows :—

Clavicle or *collar-bone* } Together forming the *shoulder* or
Scapula or *shoulder-blade* } *pectoral girdle*.

Humerus or *bone of the upper arm*.

Ulna } In the *forearm*.
Radius }

Carpal or *wrist-bones* (8)—in two rows of four each.

Metacarpal bones, in the *palm of the hand*—5 in each.

Phalanges or *finger-bones*—3 in each finger, 2 in each thumb.

The pectoral girdle is not attached to the skeleton by a firm bony union, merely muscles and connective tissue. The only really firm connection is that of the sternal end of the clavicle with the upper end of the sternum, known as the **manubrium**. Hence, owing to this laxity of connection, one can " shrug the shoulders " but not the hips. The three bones of this girdle consist of the clavicle, scapula, and coracoid process. In reptiles and birds the latter is a separate bone, while in man it has become part of the scapula. The function of the upper limb is mainly that of handling objects (prehension), though as babies we also used it as an aid to locomotion (walking on all fours). Rabbits use their fore-limbs for burrowing.

The **clavicle** (Lat. *clavis*, a key) is so called from its fancied resemblance to an ancient key. It is commonly known as the **collar-bone**. One end articulates with the top part of the sternum (the manubrium), and the other extremity forms a joint with the acromion of the scapula near its articulation with the humerus. The clavicle tends to keep the shoulders back. It is short and imperfectly formed in the rounded shoulders of the cat and the dog ; and in the horse and the sheep it is wanting. It forms, however, an essential part of the skeleton of the monkey, the squirrel, and other climbing animals.

The **scapula** or **shoulder-blade** is triangular in form ; it consists of a broad flat portion, and a prominent ridge known as the **spine** at the back of this. The front surface is smooth and concave, and glides over the back convex surface of the chest.

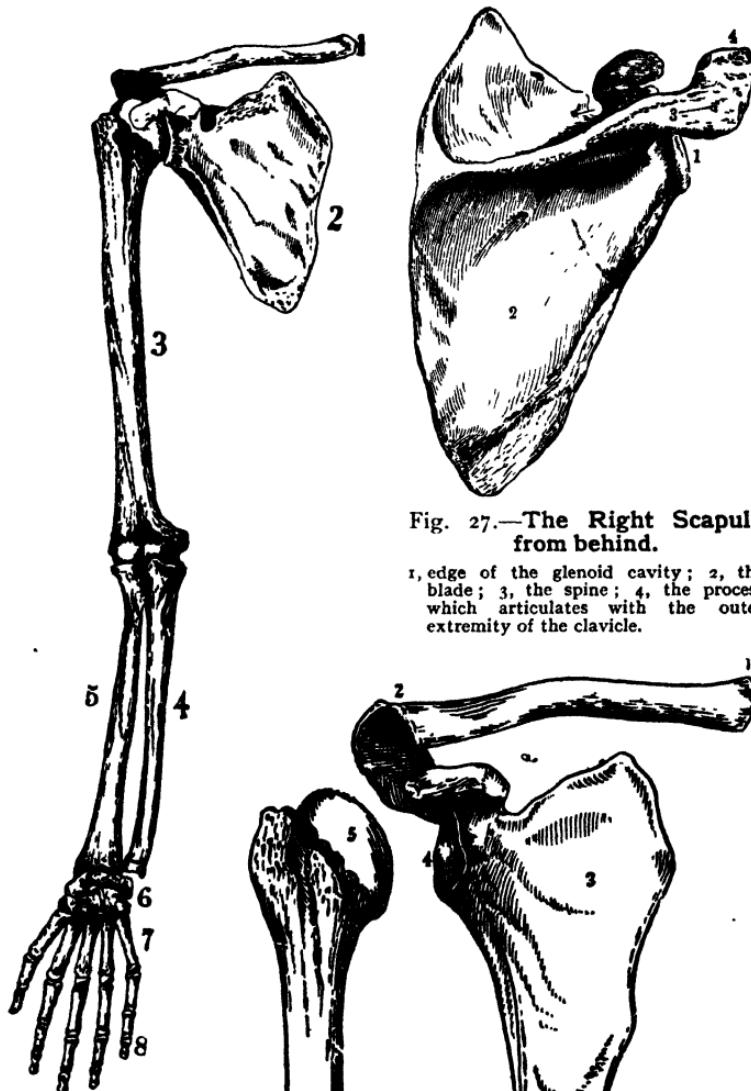


Fig. 26.—Bones of the Right Upper Limb.

1, clavicle; 2, scapula; 3, humerus; 4, ulna; 5, radius; 6, carpal bones; 7, metacarpal bones; 8, phalanges.

Fig. 27.—The Right Scapula from behind.

1, edge of the glenoid cavity; 2, the blade; 3, the spine; 4, the process which articulates with the outer extremity of the clavicle.

Fig. 28.—The Right Shoulder-Girdle and Head of the Humerus.

1, clavicle; 2, process of the scapula; 3, blade; 4, glenoid cavity; 5, head of the humerus.

The outer end of the clavicle articulates with the acromion, one of the two processes which project from the top of the scapula, and is attached to the other process by means of strong ligaments. At the upper and outer part of the scapula there is a shallow concave surface—the **glenoid cavity** (Gr. *glene*, the pupil ; and *eidos*, form)—which receives the rounded head of the bone of the upper arm. The scapula is therefore united to other bones only at or near the shoulder-joint. It has, therefore, great freedom of motion, especially as the glenoid cavity is so shallow.

The **humerus** or **bone of the upper arm** is very strong. It consists of a long portion called the *shaft*, and two enlarged extremities, the upper one being known as the *head*. As already mentioned, the upper end fits into the glenoid cavity of the scapula. The joint thus formed permits of a greater freedom of movement than any other joint in the body. This is due to the fact that the head of the humerus is much larger than the shallow cavity which receives it. On this account, too, the shoulder-joint would be very easily dislocated, were it not that the two processes of the scapula bend over the head of the humerus and prevent its getting out of joint when too great pressure is brought to bear on it, and also that it is held in place by muscles and ligaments.

In the **forearm** there are two bones—the *ulna* on the inner side and the *radius* on the outer side. The *ulna* (Lat., the elbow) is thick at its upper extremity, which forms a *hinge joint* or *ginglymus* (a joint which allows of motion of rotation in one plane only, like the hinge of a door) with the lower head of the humerus. This extremity of the ulna also sends a projection behind the humerus, forming the **olecranon process** (Gr. *olene*, the elbow ; and *kranion*, the top) or prominence of the elbow, which gives attachment to certain muscles, particularly the triceps, and prevents the forearm from moving too far back. When the muscles of the front of the arm contract, and bring the forearm towards the arm, the motion is known as *flexion*. The converse movement of stretching the arm out straight is known as *extension*. The *radius* is slender at the top, where its shallow cup-like end articulates with a convex surface known as the *capitulum*, furnished by the humerus. The head of the radius is kept in contact with the ulna by the *orbicular ligament*. The lower extremity is enlarged, and articulates with two bones of the wrist. If we rest the forearm flat on a table, with the palm of the hand uppermost (an attitude which is called *supination*),

the ulna and the radius are parallel with each other. If we now turn the hand round till its back is uppermost (*pronation*) the ulna does not change its position; but the lower end of the radius turns round this bone, crossing it, and carrying the hand with it. Thus the upper slender end of the radius rotates on a pivot formed by a rounded portion of the lower head of the

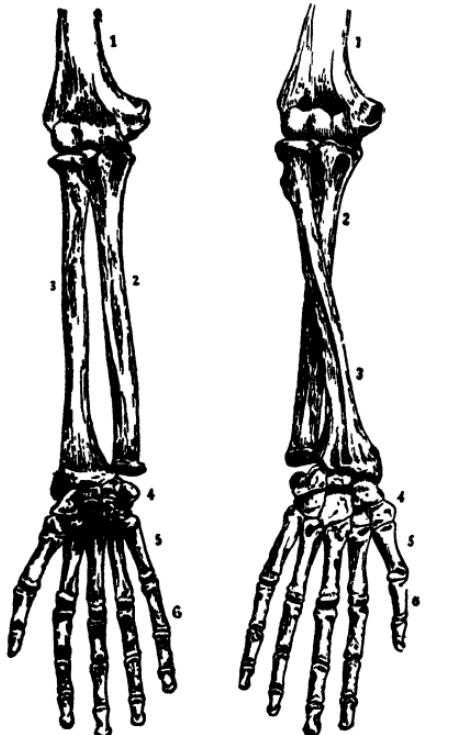


Fig. 29.—The Bones of the Right Forearm in Supination.

Fig. 30.—In Pronation.

1, humerus; 2, ulna; 3, radius; 4, carpal bones; 5, metacarpal bones; 6, phalanges.



Fig. 31.—The Bones of the Forearm, with the Orbicular Ligament.

1, ulna; 2, radius; 3, olecranon process; 4, orbicular ligament.

humerus, and is held in its position by a circular ligament, while its lower extremity revolves round the ulna. This ability to pronate and supinate has been the means of a great advance in evolution, especially in regard to human inventions.

The **wrist** or **carpus** is composed of *eight* small bones, called **carpal bones** (Gr. *karpos*, the wrist), arranged in two rows of

four, of which the upper is united to the radius, while the second row articulates with the metacarpals. These bones are united with one another and with the neighbouring bones by means of ligaments in such a manner that each one is capable of a slight gliding motion. The wrist is thus rendered flexible ; and this flexibility, combined with the rotatory motion of the radius, gives great freedom of movement to the hand.

Five long bones, called **metacarpal bones** (Gr. *meta*, beyond; *karpos*, the wrist), form the palm of the hand. One of these passes from the wrist to the thumb, and the other four from the wrist to the fingers. These bones may be easily felt by pressing the fingers of one hand over the back of the other. It will, of course, be observed that the metacarpal bone which is connected with the thumb is capable of motion to a far greater degree than the others. It may indeed be regarded as the first phalanx. It is on this that the utility of the thumb depends, for we are enabled to move the thumb round till it is in opposition to the fingers, and thus to firmly grasp large objects and to pick up small ones.

The **phalanges** (Gr. *phalanx*, a line of soldiers ; a rank) of the fingers are united to the metacarpal bones. There are three of these in each finger and two in the thumb, making a total of fourteen for each hand.

THE PELVIC GIRDLE AND THE LOWER LIMB.

—If a foetal hip-bone is examined it will likewise be found to be made up of three bones—the **ilium**, **ischium** and **pubis**. They unite at the centre, thus \wedge , to form a deep cavity known as the **acetabulum**, into which fits the head of the femur, or long bone of the thigh. The two pubic bones unite in front (ventrally), each with its fellow of the opposite side. Posteriorly the ilia are separated by the wedge-shaped mass of the sacrum. The whole thus forms a basin-shaped cavity, known as the **pelvis**, which holds some of the intestines, the urinary bladder,

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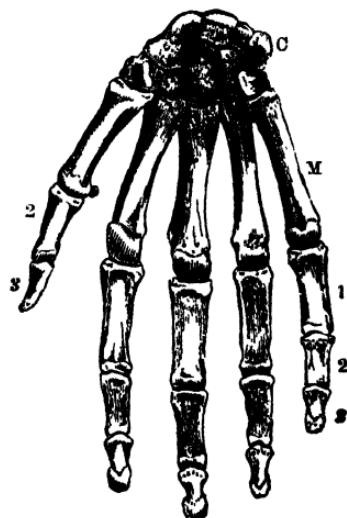


Fig. 32.—The Right Hand, palmar surface.

c, carpal bones ; m, metacarpal bones
1, 2 and 3, phalanges.

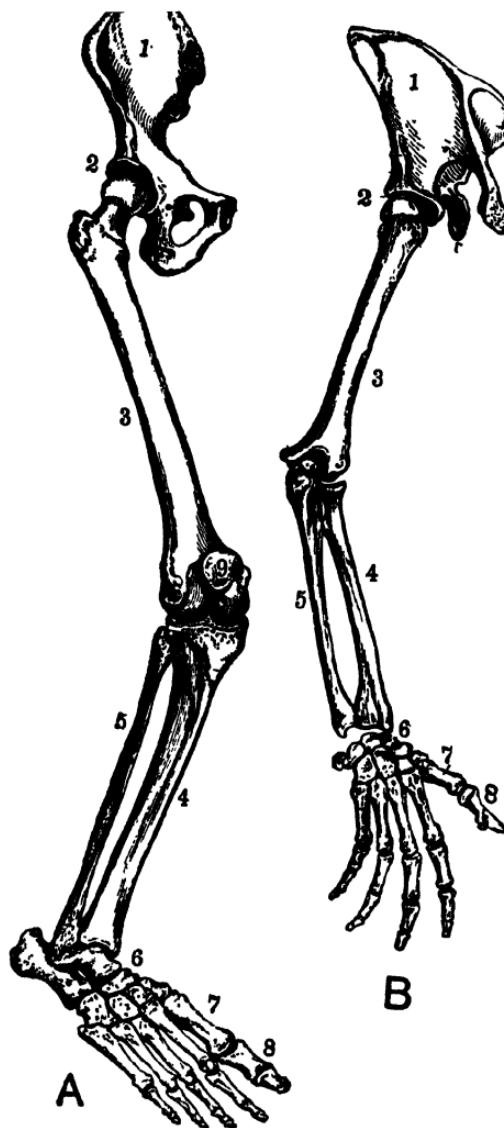


Fig. 33.—The Bones of the Upper and Lower Limbs placed to show corresponding parts.

A, The Lower Limb.

- 1, os innominatum.
- 2, acetabulum.
- 3, femur.
- 4, tibia { lower leg.
- 5, fibula {
- 6, tarsus or ankle—7 bones.
- 7, metatarsus.
- 8, phalanges of toes.
- 9, patella.

B, The Upper Limb.

- 1, scapula.
 - 2, glenoid cavity.
 - 3, humerus.
 - 4, radius { forearm.
 - 5, ulna {
 - 6, carpus or wrist—8 bones.
 - 7, metacarpus.
 - 8, phalanges of fingers.
- The patella has no corresponding part in the arm.

and the organs of reproduction. The scapula and ilium thus correspond to or are homologous with each other ; similarly the coracoid and ischium correspond, as do the clavicle and pubis. The arrangement of the bones of the lower limb is similar to that described for the upper limb, with certain modifications due to the fact that it is both an organ of locomotion, and of support. It articulates with the vertebral column (sacral region), and also it is more complete than the pectoral girdle.

The **obturator foramen** is a large aperture between the pubis and ischium ; a strong membrane covers it. Through it some important vessels and nerves pass out from the pelvis to the leg.

The bones forming the above are :—

- Pelvic or *hip-bones*, forming the pelvic or hip-girdle.
- Femur or *thigh-bone*.
- Patella or *knee-cap*.
- Tibia or *shin-bone*. } The bones of the *leg*.
- Fibula or *splint-bone*. }
- Tarsal or *ankle-bones* (7).
- Metatarsal or *instep-bones*. }
- Phalanges or *toe-bones*. } The bones of the *foot*.

The **pelvic or hip-bones** are also called the **osssa innominata** or **innominate bones** (Lat. *in*, not ; and *nomen*, a name). If we examine these in the skeleton of a young child, we find that each *os innominatum* is composed of three distinct parts, which meet at a deep cup-like depression called the **acetabulum** (Lat., a cup for holding vinegar). The broad upper portion is called the **ilium** (Gr. *eileo*, I twist) ; the lower part, the **ischium** (Gr. *ischion*, the hip) ; and that portion which is joined to the other innominate bone, the **pubis**—as has been explained above. The lower and hinder portion of the ischium has an enlargement known as the *tuberosity of the ischium*. It is upon these that we sit down. The articulation between the two pubic bones is known as the *symphysis pubis*.

The **acetabulum** receives the rounded head of the thigh-bone. The bones of the pelvis are supported like a bridge on the legs as pillars, and serve in turn as a support for the internal organs of the *abdomen* and *pelvis*.

There are marked differences in the size and shape of the male and female pelvis, due to the adaptation of the latter to the processes which occur when baby is being born (parturition).

The **femur or thigh-bone** corresponds with the humerus of

the arm. In general form it resembles that bone, but is much larger and stronger, having to bear the weight of the body. In fact it is the strongest and largest bone in the body. Its upper

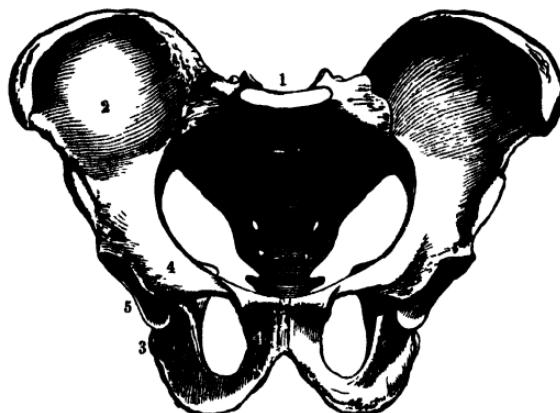


Fig. 34.—The Male Pelvis and Sacrum, seen from before.
1, sacrum ; 2, ilium ; 3, ischium ; 4, pubis ; 5, acetabulum.

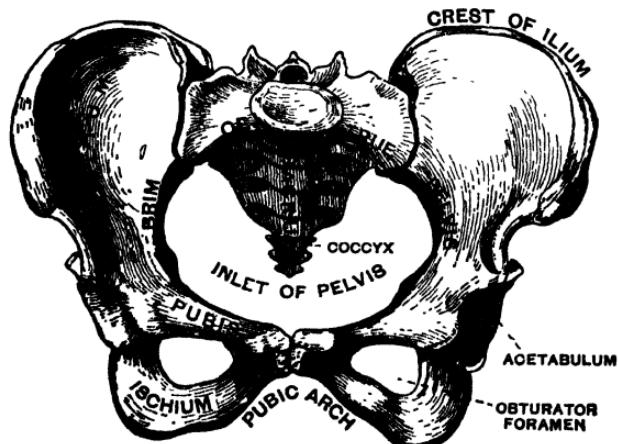


Fig. 35.—The Female Pelvis—Sacrum, Coccyx, and the two Innominate Bones.

extremity is provided with a rounded head which articulates with the acetabulum of the hip-bone, forming a *ball-and-socket joint*, somewhat similar to that of the upper arm, but differing in one important respect. The rounded head of the femur is

much more prominent than that of the humerus, and the acetabulum is much deeper than the glenoid cavity of the scapula.

Thus the thigh has not the freedom of motion of the humerus, and is kept in position by much more powerful muscles. It is therefore less easily dislocated. The lower end of the femur is broadened out so as to articulate with the tibia. It should be noted that this bone is not vertical when the body is in the erect posture. As one proceeds downwards from the pelvis, the two femora approach each other. Since the width of the female pelvis is greater than that of the male, the degree of inclination of the femora is therefore greater in the female than in the male. As a further consequence the neck of the femur forms a lesser angle with its shaft in the female

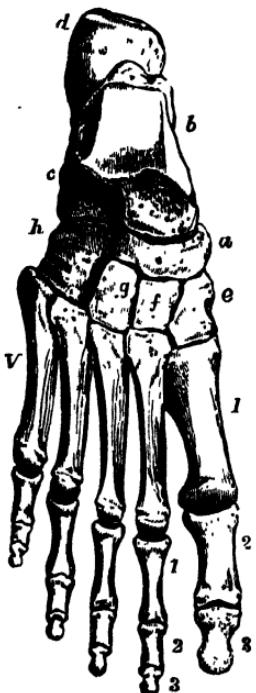


Fig. 36.—Right Foot, viewed from above.

a, navicular; b, astragalus; c, os calcis; e, first cuneiform; f, second cuneiform; g, third cuneiform; h, cuboid. I to V, metatarsal bones; 1 to 3, phalanges of great toe; 1, 2 and 3, phalanges of second toe.

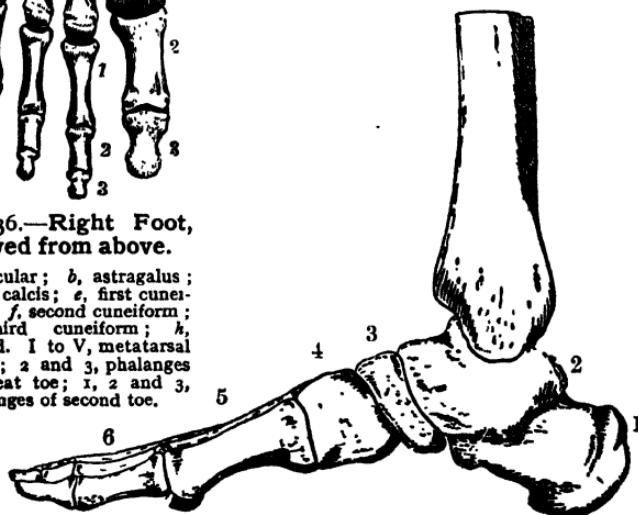


Fig. 37.—The Bones of the Right Foot, viewed from the inner side, showing the arched form.

1, os calcis; 2, astragalus; 3, navicular; 4, first cuneiform; 5, first metatarsal; 6, phalanges.

than it does in the male. These points of difference are often of very great importance in the investigation of crime.

The **leg-bones**, like those of the forearm, are two in number—the **tibia** or **shin-bone**, and the **fibula** (Lat., a *clasp* or *buckle*) or **splint-bone**. These bones correspond with the radius and ulna for the tibia is preaxial, and the fibula postaxial, but the fibula does not rotate round the tibia as does the radius round the ulna ; hence there can be no pronation or supination of these bones ; it is slender throughout its length, and is firmly fixed to the tibia at both ends. The tibia forms, with the femur, the hinged **knee-joint** which corresponds with the similar joint of the elbow. Like the latter, it is a ginglymus, or a rotation in one plane.

The lower rounded end of the tibia felt as a projection on the inner side of the leg is the *internal malleolus*, while the corresponding projection on the fibula is the *external malleolus*.

The **knee-joint** is protected by a small bone, the **patella** (Lat., a little plate), called also the **knee-cap** or **knee-pan**.

The **bones of the foot** consist of the **tarsal** or **ankle-bones**, the **metatarsal** or **instep-bones**, and the **phalanges** of the toes. The **tarsal bones** are seven in number. One of them



Fig. 38.—Imprint of the Sole of a Foot.

is much larger than the others, and, projecting backward, forms the **heel**. It is therefore called the *os calcis*. The **metatarsal bones** are similar to the metacarpal bones of the hand, and form the sole of the foot. They are five in number, and are connected with the **phalanges** of the toes. The number of bones in the toes is the same as in the fingers and thumb, the great toe representing the thumb. Its degree of mobility is, however, far less, but it should be noted that by training from an early age it can be made almost equivalent to a thumb.

The **foot** is arched in form, and is prevented from falling flat by powerful ligaments. This arched form gives great strength combined with elasticity. Any weakening of these ligaments, as can occur in certain diseases, leads therefore to the development of **flat foot**. In this condition there is a lowering

of the arch of the foot, together with abduction and eversion.

DIGITAL FORMULÆ.—It is convenient to designate briefly the number and arrangement of the phalanges of the two limbs by a “formula.” Thus, starting with the anterior limb, thumb side, we may jot down the phalanges as 2.3.3.3-3-2.3.3.3.3. In the case of the frog it is 0.2.2.3.3-2.2.3.4.3, showing a greater development in the hind limb correlated with its great power of leaping, while in the rabbit it is 2.3.3.3.3-0.3.3.3.3.

SUMMARY

THE UPPER LIMB (64 bones).

Pectoral-girdle (shoulder)	Clavicle	Articulates with manubrium and acromion. Blade, spine.
	Scapula	Glenoid cavity—articulates with humerus. Two processes—acromion, coracoid.
Upper arm	Humerus	Head—articulates with glenoid cavity. Lower end—articulates with radius, ulna.
	Ulna	Large head—articulates with humerus. Lower end—articulates with radius.
Forearm	Radius	Small head—bound to ulna by ligament. Articulates with humerus and ulna.
	Carpus (wrist)	Large lower end articulates with the scaphoid and semilunar bones. 8 bones in two rows:— Scaphoid, semilunar, cuneiform, pisiform. Trapezium, trapezoid, os magnum. unciform.
Hand	Metacarpus	5 bones, connecting fingers with wrist.
	Phalanges	14 bones→2.3.3.3.3, as in the toes.

THE LOWER LIMB (62 bones).

Pelvic girdle (hip)	Ilium	Two Ossa innominata—each is a fusion of 3 bones : Ilium, Ischium, Pubis.
	Ischium	Acetabulum—cavity for head of femur.
	Pubis	Obturator foramen—for nerves and vessels.
Thigh	Femur	Head articulates with acetabulum. Lower end articulates with tibia, patella.
Knee-cap	Patella	In tendon of quadriceps femoris.
	Tibia	Head articulates with fibula and femur. Lower end articulates with fibula and astragalus.
Leg	Fibula	Fixed to tibia at both ends, very slender. Articulates with the tibia and astragalus
	Tarsus (ankle)	7 bones in two rows:— Os calcis, astragalus, navicular; Cuboid, three cuneiforms.
Foot	Metatarsus	5 bones, connecting toes with ankle.
	Phalanges	14 bones→2.3.3.3.3, as in the fingers.

CHAPTER V

LIGAMENTS. CARTILAGE. JOINTS

LIGAMENTS.—Ligaments are strong, white, fibrous bands which bind the articular surfaces of bones together. Being flexible, they allow of the necessary freedom of motion to the

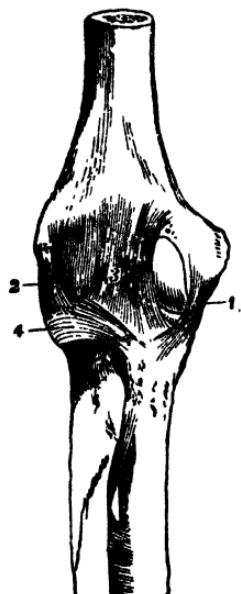


Fig. 39.—The Ligaments of the Elbow-Joint, from the front.
1, 2, 3 and 4, the ligaments.

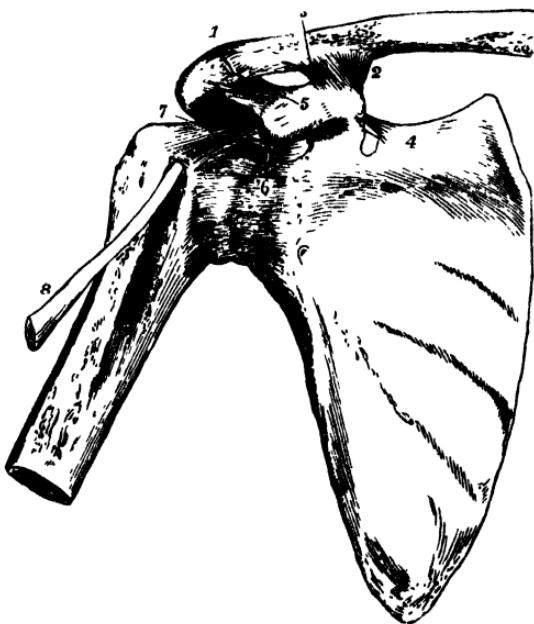


Fig. 40.—The Shoulder-Joint, showing Ligaments and Tendon.
1 to 7, ligaments of the shoulder; 8, a tendon of the biceps (long head).

bones, and at the same time protect the joints from external injury and tend to prevent dislocation.

These ligamentous bands may easily be observed by carefully removing the flesh from a cooked rabbit, fowl or joint of meat. It may be noticed at the same time that the masses of flesh (muscles) are united to the bones by other white bands. These

are called **tendons** or **sinews**, and they must not be confused with ligaments, which always bind bone to bone and are elastic. Tendons serve to attach the skeletal muscles to the periosteum of bone.

CARTILAGE—Cartilage (Lat., *cartilago*, gristle) is a firm,

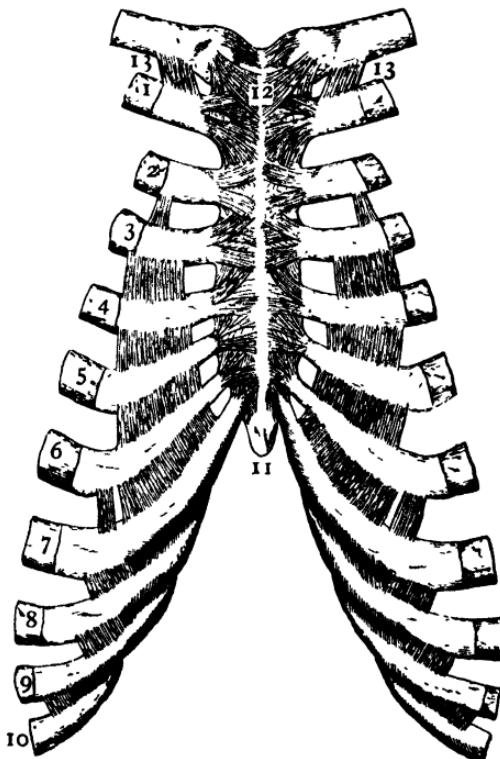


Fig. 41.—The Ligaments and Cartilages of the Chest.

1 to 10, the anterior ends of the ribs, with their costal cartilages, and the ligaments uniting them; 11, ensiform process, or cartilaginous end of the sternum; 12, ligaments uniting the clavicle with the sternum; 13, ligaments binding the clavicle to the first rib.

tough and flexible substance which covers the articular surfaces of bones, and unites the ribs to the sternum. It is also found in the walls of the trachea. Bone is produced by the gradual hardening of cartilage or, more strictly, by the gradual deposition of lime salts in the substance (matrix) of cartilage. The skeleton of a very young animal or a new-born baby consists almost entirely

of cartilage, and as the animal develops into maturity the bones become gradually harder by the slow absorption of mineral matter derived from its food substances, till at last the skeleton consists almost entirely of bone.

Cartilage is not supplied with blood, hence it is white or semi-transparent. When boiled for some time with water, it yields a substance called **chondrin** (Gr. *chondros*, cartilage), which closely resembles gelatin, being soluble in hot water and forming a "jelly" on cooling.

Those cartilages which are converted into bone during growth are called **temporary cartilages**; whilst those which remain unchanged are **permanent cartilages**.

THE USES OF CARTILAGE are various. It is *tough*, *flexible* and *elastic*, and will be found in all parts of the body where these properties are essential. Sometimes it helps to form a flexible framework, as in the **costal cartilages** of the walls of the chest, the larynx and trachea. The **intervertebral cartilages** of the backbone are flexible pads which bind the vertebræ together, at the same time allowing a certain degree of movement, enabling us to bend the back. In aged persons these cartilages become hardened by the absorption of lime, hence the stiffness of the vertebral column. They also act as *buffers* in deadening the effect of a blow or shock. Another use of cartilage is to deepen the bony sockets of various joints by surrounding them at their edges in the form of a ring. This is especially the case with the acetabulum. The sockets thus deepened are better enabled to hold the rounded heads of the bones which move in them, and, the cartilage being flexible and elastic, the motion is not restricted. Cartilage also lines the surfaces of bones which glide over each other. In such cases the cartilaginous surfaces are smooth, thus making the motion easier. The cartilage which serves this purpose is called **articular cartilage**.

JOINTS OR ARTICULATIONS are the connections between adjacent bones. They are distinguished as *immovable*, *movable* and *slightly movable*.

1. **Immovable joints** are those in which the bones are in actual contact, *i.e.* without any intervening cartilage; and are incapable of motion on each other. In some such joints, as in the skull, each bone has a very irregular sawlike edge, and the teeth or projections of the opposite edges are firmly dovetailed together. Such joints are known as **sutures** (Lat. *sutura*, a seam). If you look at a baby's head, the sutures will not have

fully united, particularly at two areas on the top called the **anterior and posterior fontanelles.** (See page 22.)

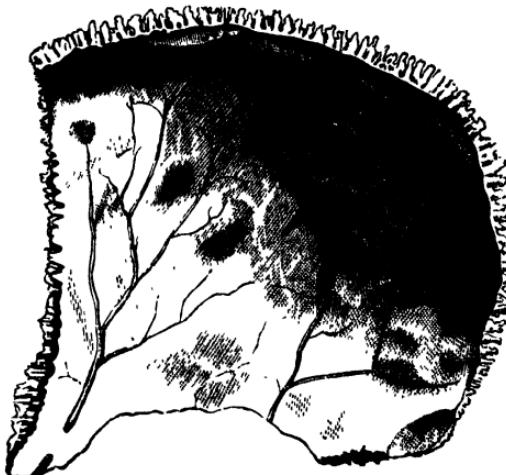


Fig. 42.—Inner Surface of the Right Parietal Bone.

Note the irregular, notched edges of the sutures, and the grooves for the middle meningeal arteries.

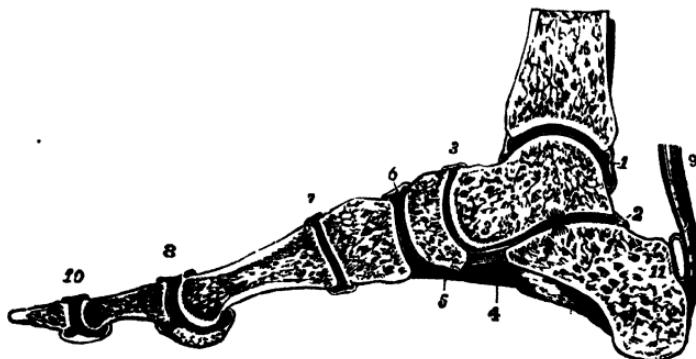


Fig. 43.—Section of the Right Foot.

Showing the nature of a sliding or gliding joint, synovial membranes and synovial cavities ; ligament and tendon, also the arched form of the foot.
1, 2, 3, 6, 7, 8 and 10, synovial cavities, surrounded by synovial membrane ; 4 and 5, ligaments ; 9, tendo, Achilles.

2. Movable joints are those in which the bones forming them are capable of motion against each other. Most of the

joints in the body are of this type. They are subdivided into *perfect* or *complete*, and *imperfect* or *incomplete*.

(a) The perfect joints are of four kinds, viz. :—(1) **gliding joints** or **arthrodia**, consisting of bones which slide over each other, as those of the ankle and wrist ; (2) **enarthrodia** or **ball and socket joints**, consisting of a rounded head which rotates in a hollow socket, and so allows of movement in all directions, as the hip-joint and shoulder-joint ; (3) **ginglymus** or **hinge-joint**, like those of the elbow, knee, phalanges and ankle ; and

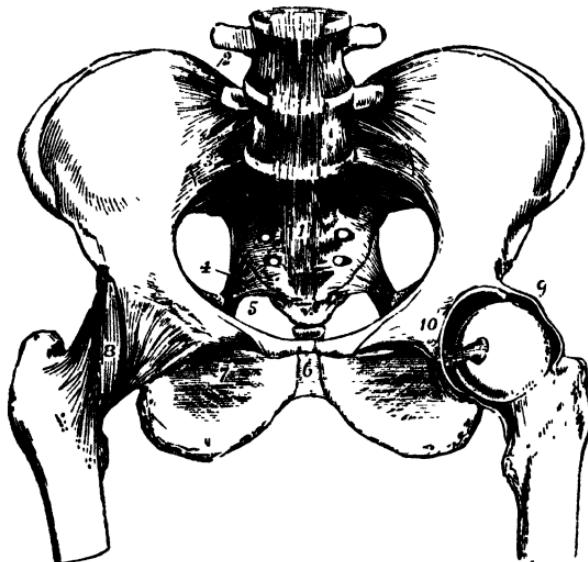


Fig. 44.—The Joints of the Pelvis.

1, ligament of the vertebræ ; 2, 3, 4, 5, 6, 7 and 8, other ligaments ; 9 and 10, ball-and-socket joint of the hip in part dissected, to show the synovial cavity ; and also the ligament (*ligamentum teres*) which connects the head of the femur with the interior of the acetabulum.

(4) **trochoid** or **pivot-joints**, in which a projection of one bone serves as a pivot for the rotation of the other, as the joint formed by the atlas and the axis, or the rotation of the radius on the ulna.

In each of these joints the articulating surfaces of the bones are covered with a thin layer of articular cartilage, the rest of the joint being lined with a membrane called the **synovial membrane** (Gr. *syn*, together ; and *oon*, an egg), from which exudes a fluid (*synovia*) resembling the white of egg, the use of which is to lubricate or moisten the joints. The synovial

membrane forms a closed sac or cavity, called the **synovial cavity**, which contains the synovia.

(b) An imperfectly movable joint, **amphiarthrosis**, is one in which the bones are separated from each other by a layer of cartilage. The bones, therefore, do not move on each other, but all motion is due to the flexibility of the layer of cartilage between them. The vertebrae with the intervertebral cartilages, and the symphysis pubis, form such joints.

TYPES OF JOINT MOVEMENT.—There are various sorts of movements in joints :—

1. *Angular movement*, between the long bones. If this movement is forwards and backwards it is called **flexion** and

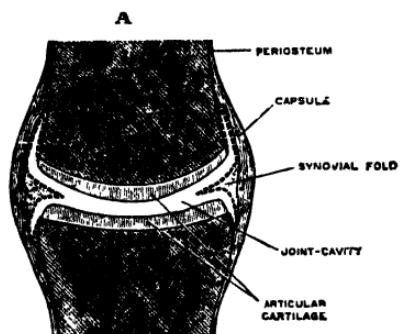


Fig. 45.—Section showing the structure of a Joint.

The dotted line represents the synovial membrane. The articular surfaces are in reality in contact.



Fig. 46.—Section through the Pivot Joint formed by the Atlas and the Axis.

1, section through the odontoid peg, showing synovial cavities before and behind ; 2, cut portion of the atlas ; 3, the transverse ligament which holds the peg ; 4, surface of the atlas which articulates with the skull.

extension, while if it allows of movement to or from the median plane of the body it is called **adduction** or **abduction**.

2. *Gliding movements* only, no rotation. It is the simplest kind that can occur, and is the only possible motion in some joints, such as the wrist and ankle.

3. *Circumduction*, when the bone describes a conical space such as is seen in the hip, shoulder and thumb-joints.

4. *Rotation* of a bone round a more or less central axis, as in the motion of the radius round the ulna, and the atlas around the odontoid peg of the axis.

It should, however, be pointed out that these movements are usually more or less combined in the various joints.

SUMMARY

1. **Ligaments** bind bones together, and are slightly elastic.
 2. **Tendons** connect voluntary muscles with bones, and are inelastic.
 3. **Cartilage** is tough, flexible and elastic. When boiled it yields *chondrin*, which resembles gelatin. Chondrin is insoluble in cold water, but dissolves in hot water, forming gelatin on cooling.
 4. **Kinds of Cartilage** :—
 - a. *Temporary*—foetal, becomes converted into bone in adults.
 - b. *Permanent*—not converted into bone—costal, sternal, tracheal.
 5. **Uses of Cartilage** :—
 - a. Forms strong yet flexible framework—thorax, trachea.
 - b. Acts as buffers in deadening shocks—intervertebral discs.
 - c. Deepens the sockets of joints—the hip-joint.
 - d. Covers the articulating surfaces of bones, reducing friction.
 6. **Joints**—the connections between bones.
 - a. *Immovable*—sutures (skull) and teeth.
 - b. *Movable*—these may be perfect or imperfect
Perfect—gliding (ankle, wrist).
ball and socket (shoulder, hip).
hinged (elbow, knee, ankle).
pivoted (radius-ulna, atlas-axis).
Imperfect—vertebral joints.
- Movements*—angular, gliding, circumduction, rotation.

CHAPTER VI

BONE, MARROW AND PERIOSTEUM

THE COMPOSITION OF BONE.—Weigh a clean, dry bone of a rabbit, sheep or other animal, and then put it into a hot and clear fire. Let it remain till it is at a red heat throughout. Now remove it carefully from the fire, let it cool, and weigh again. It will be noticed that the bone has lost about one-third of its original weight, and that what remains is a white and brittle substance. That which has been burnt away by the fire is the **organic** or **animal matter** of the bone ; while that which remains is the **earthy** or **mineral substance**, sometimes called the **ash**. From this we learn that bone consists of about 33 per cent. of animal matter, and about 67 per cent. of mineral matter. The inorganic constituents are **calcium phosphate**, $\text{Ca}_3(\text{PO}_4)_2$, chiefly and a little **calcium carbonate**, CaCO_3 .

The proportion of animal to mineral substance is not the same in all bones. The flexible bones of a young child also contain little mineral substance, while the bones of elderly persons lose some of their mineral matter and become porous. Hence the possibility of "green-stick" fractures in the young, and "spontaneous" fractures in the aged.

In the above experiment we completely destroyed the animal matter, and obtained the pure mineral substance or **bone ash**. By the following experiment we shall be able to dissolve out all the mineral substance, and thus obtain the **animal matter** :—

Place a bone taken from a recently killed animal in a vessel of weak **hydrochloric acid** (one part of the strong acid to about six of water) and let it remain for a day or two completely covered by the acid. Now pour off the liquid, and cover the bone with fresh acid, setting it aside again for some time. It will be noticed that the bone gradually becomes softer under this treatment, till at last it is flexible and elastic, like a piece of indiarubber. This is due to the gradual removal of the mineral substance it contained. This experiment teaches us that the **hardness of bone** is due to its **mineral matter**, and that the **animal substance** resembles **cartilage** or **gristle**. The organic constituent is **collagen** chiefly.

In this experiment we notice also that the mass of animal matter retains the form of the bone from which it was obtained.

In our first experiment, too, we found that the mass of mineral substance was also of the same form as the bone. Hence we conclude that **both animal and mineral substances are well blended together** in the bones. A bone which has had its earthy salts dissolved out is said to be **decalcified**.

The collagen may be converted into gelatin in the following manner :—

Take some bones that have been recently removed from the body of an animal, break them in pieces, and boil them in water for a considerable time. After this pour off the liquid and let it cool. As it does so it will form a *jelly*. The animal matter of the bone, *i.e.* the collagen, has been partially separated by prolonged boiling, and has been converted into gelatin.

THE SHAPES OF BONES.—While studying the skeleton the student will have noticed that the different bones of the body vary considerably in shape. They are generally classified as—

1. **Long bones**, as the femur, humerus, metacarpals radius, metatarsals ulna, tibia and fibula. They are found in the limbs.

2. **Short bones**, as those of the wrist and ankle, where great strength combined with limited movement is required.

3. **Flat bones**, as those of the top of the skull, the scapula, sternum, ribs and ossa innominata. They consist of two thin layers of compact bone, with cancellous bone between. Such bones are intended for protective purposes as well as for muscular attachment.

4. **Irregular bones**, as the vertebrae, sacrum, coccyx, hyoid and the bones of the face.

The long bones, like the femur, tibia, etc., consist of a *shaft* or *diaphysis*, terminating at each end in an extremity (upper and lower). These ends are usually expanded so that they

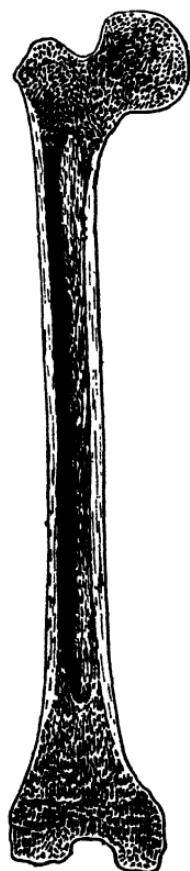


Fig. 47.—**Longitudinal Section of the Femur, showing the Compact and Cancellous Tissues, and the Medullary Cavity.**

can articulate. Bones grow in length from special growing areas, known as centres of ossification, which are found in the ends, called *epiphyses*. Growth in width occurs from the periosteum.

Short bones have one ossifying centre, while long bones have one for the body and one or more for each end. Any damage to these centres may seriously affect the normal growth of the bone, and the functional utility of the limb concerned.

THE STRUCTURE OF BONES.—Take a long bone, such as the femur (which should be from an animal recently killed), and saw it longitudinally into halves. Now look at the section and examine the structure of the bone, comparing it

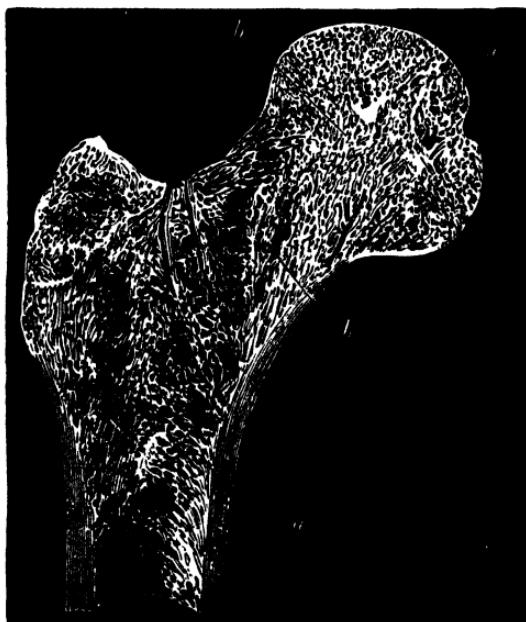


Fig. 48.—Section of the head of the Femur
a, compact tissue ; *b*, cancellous tissue.

with the diagrams (figs. 47, 48). It will be seen that the bone consists of two distinct kinds of substance. Its outer portion is composed of a very hard and compact substance, somewhat resembling ivory. This is called **compact** or **dense bony tissue**. It is thickest along the shaft, and is very thin around the heads. Note also that the extremities are expanded for the purpose of articulation and for the attachment of muscles. The heads of bones are filled with a less compact mass, which is so porous that it is described as **spongy** or **cancellous** (Lat. *cancelli*,

a grating) **tissue**. In addition to these two kinds of tissue, the central cavity of the bone contains a soft pulpy substance, the **marrow**; while the cavity itself is called the **medullary cavity**.

The **short** and the **irregular bones** have no medullary cavity, but consist of a thin outer layer of compact tissue, filled in with cancellous tissue. They are intended for strength and compactness combined with limited movement. Examples are the **carpus** and **tarsus**. The **flat bones** consist of a layer of cancellous tissue between two layers of the compact tissue. These

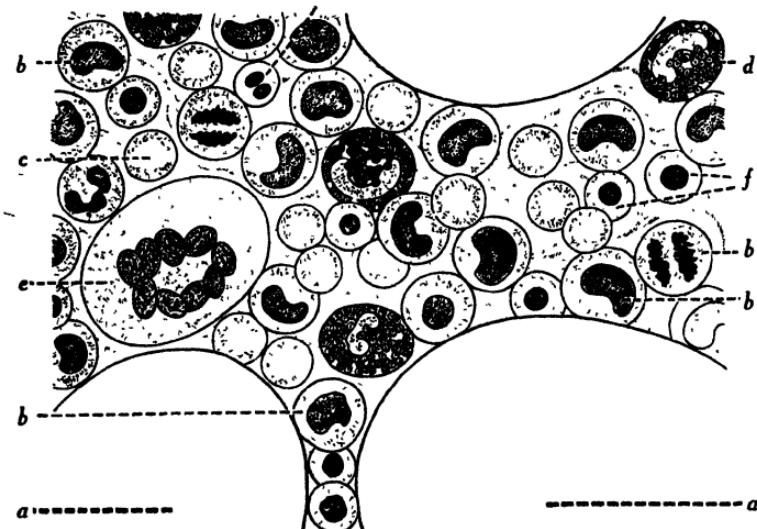


Fig. 49.—Human Bone-marrow highly magnified.

a, fat cells; **b**, myelocytes; **c**, red cell (erythrocyte); **d**, eosinophil; **e**, giant cell (myeloplax); **f**, normoblasts.

bones are found where the chief requirements are protection or else a broad surface for the attachment of muscles, as in the scapula and skull.

BONE MARROW is of two distinct varieties :—

1. **Red marrow** is found in the cancellous tissue of bone at any age, and in the medullary cavity of long bones in the **fœtus** and child. It is very red in colour, due to its great vascularity. On examination with the microscope it will be seen to be composed of a mass of cells of different sorts: (a) The majority of them (75 per cent.) are **marrow cells** (myelocytes,

Gk. *muelon*, marrow). They are amoeboid and produce the ordinary leucocytes of the blood. These cells are produced outside the marrow capillaries and migrate into them. (b) Erythroblasts (25 per cent.) or nucleated red corpuscles. They are derived from the cells lining the capillary walls and eventually become the ordinary red corpuscles of the blood. Red marrow persists in the ribs, sternum and vertebræ throughout life.

2. **Yellow marrow** fills the medullary cavities of the long bones in adults. It mostly consists of fat cells (hence the colour), though there are a few myelocytes to be found.

PERIOSTEUM.—That part of a bone which assists in forming a joint is covered with a smooth layer of articular cartilage. The remainder of the surface is covered with a tough and fibrous membrane, called periosteum (Gr. *peri*, around, and *osteon*, a bone). It is really composed of two layers. The outer is of connective tissue. It is to this that the tendons of muscles which move bones are connected. The inner layer is of elastic tissue. It also contains special cells whose purpose is to produce the growth of bone in width, i.e. it is osteogenetic. There is, however, some difference of opinion in regard to the origin of these cells.

Blood is supplied to the bone by small vessels from this periosteum, which pierce the bone underneath it. Also in this way nerves and lymphatics pass from the bone substance. Other small vessels pierce the articular extremities, and pass to the cancellous tissue. It will thus be realised that a bone and its cavity are well supplied with blood-vessels. There is a proper nutrient artery (or arteries) to each bone. They supply the marrow, while other blood-vessels proceed to the extremities for the supply of the cancellous tissue found there.

The circulation of blood *within* the substance of the bone is brought about by a capillary system which is lodged in countless minute canals, to be found in all parts of the bone.

SUMMARY .

COMPOSITION OF BONE, $\frac{1}{3}$ animal, $\frac{2}{3}$ mineral matter.

1. **Mineral matter**—soluble in HCl, forms ash when bone is burnt.

$\text{Ca}_3(\text{PO}_4)_2$, 90 per cent., CaCO_3 , 10 per cent.

Little in child's bones (greenstick fractures); diminished by resorption in old age (spontaneous fractures).

2. **Animal matter**—mostly collagen, yields gelatin on boiling.

Devoid of lime salts, bone becomes flexible and elastic.

STRUCTURE OF BONE.

1. **Long bones**—in the limbs—all bones except carpal and tarsals.
 - a. Shaft—cylindrical, wall is compact bone.
 - b. Medullary cavity—for marrow (yellow or red).
 - c. Extremities—expanded for articulation, muscular attachment.
Is cancellous—contains red marrow.
2. **Short bones**—for strength—wrist, ankle, patellæ.
Thin outer layer compact bone, cancellous within.
3. **Flat bones**—protective and for muscular attachment.
Skull bones, ribs, sternum, scapula.
4. **Irregular bones**—strength and support—vertebræ, face bones.
5. **Investment of bone.**
 - a. Articular cartilage—smooth to diminish friction, elastic.
 - b. Synovial membrane—secretes fluid to lessen friction.
 - c. Periosteum—for nourishment, growth (in width), and for repair (if fractured).
6. **Centres of ossification**—for growth, in length (epiphyses).
Important in estimating age in medico-legal cases and surgery.

BONE MARROW of two varieties :—

1. **Red marrow**—in medullary cavity long bones of children and in cancellous bone of adults.
Myelocytes—the ancestors of leucocytes.
Erythroblasts—the ancestors of erythrocytes.
2. **Yellow marrow**—in medullary cavity of adult long bones, consists mostly of fat cells.

CHAPTER VII

MOVEMENT

ONE of the essential characteristics of all living matter is its irritability or excitability, that is, its response to some external means or stimulus. The response may be in various ways, thus the cells composing a gland may be caused to secrete, a nerve to conduct a nerve impulse, leucocytes to change their shape, ciliated cells to carry out wave-like movements, and muscle to contract. In particular, we are concerned with the study of types of movement found in the human body, and the nature of the organs which produce them. These are :—

1. **Amœboid movement**—made by many unicellular organisms, such as the leucocytes of the blood.

2. **Ciliary movement**—produced by minute threads called cilia (Lat. *cilium*, an eyelash) which project from certain cells. By their to-and-fro motion they produce mass movement of liquid over their surface in one direction.

3. **Muscular movement**—brought about by the contraction and relaxation of a specially developed tissue—muscle fibres.

MUSCULAR MOVEMENT.—The particular nature of the response of a muscle to a stimulus is shown by its contractility. The really fundamental action of muscle is to produce increase of tension between its two ends, leading to a change in length (shortening) and shape, for it also thickens since its volume is unaltered. We first study the general effects of muscular action, and then the particular characteristics of each of the three varieties of muscle, skeletal, cardiac and plain.

THE STUDY OF MUSCULAR ACTIVITY may be carried out in several ways ;—

1. **The use of the body as a whole**, and the noting of the effects shown in a human being undergoing muscular exercise. We must determine the relation of the exertion to the increased pulse, breath rate, temperature and blood-pressure. Also we should note the intake of oxygen, the output of heat and CO₂, the energy expenditure, and its efficiency, the rapidity with which fatigue comes on, and the rate of recovery. All these points

are of interest not only to physiologists, but have an important bearing on industry, sports, and the clinical examination of a patient who is ill, or is a candidate for the Civil Service, or an insurance policy.

2. The Use of an Isolated Muscle.—For this purpose we excise one muscle from the body of a recently killed animal, usually a frog or other amphibian, because it possesses many practical advantages. Then we cause that muscle to be stimulated under a variety of experimental conditions, with a view to the elucidation of the nature and effects of muscular contraction. In general, there are certain characters which all types of muscle show, though there are details of difference

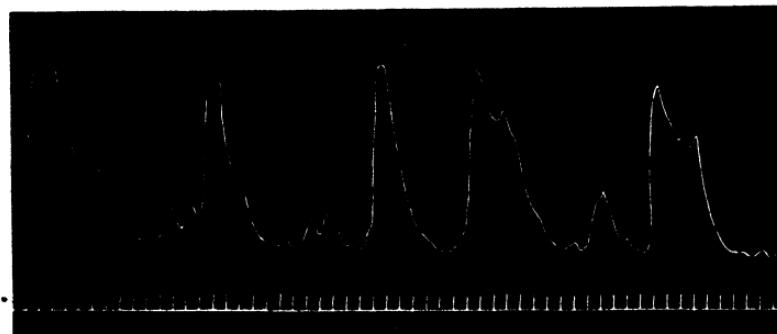


Fig. 50.—**Spontaneous Movements of Excised Uterus (Guinea Pig).**
Time marker = seconds. Upstroke = contraction.

shown by each variety. Hence three types of experiments are needed :—

(a) Cut out a uterus or a portion of plain muscle, such as a piece of an artery or gut (either longitudinally or circularly) and then determine the nature of its contractions and the circumstances which affect it (fig. 50).

(b) Excise an individual skeletal muscle—usually the sartorius or gastrocnemius (fig. 51). Then study the details of the contractions under various conditions, such as load, temperature and strength of stimulus.

The diagram is an actual tracing of a muscle twitch, using a frog's gastrocnemius and electrical stimulation *via* its sciatic nerve.

(c) Remove a heart and study the nature of its muscular contractions, as above (fig. 115).

THE GENERAL EFFECTS PRODUCED IN CONTRACTING MUSCLE.—It is convenient to consider here the various effects which occur when muscle contracts. For convenience they may be divided into physical and chemical.

1. **Physical changes**, the chief of which are :—

- (a) Alterations in the form of the muscle—the muscle shortens, its volume is unaltered, and hence it thickens.
- (b) Work is done—the muscle develops a tension by which it can lift a load, or produce movement of some sort.

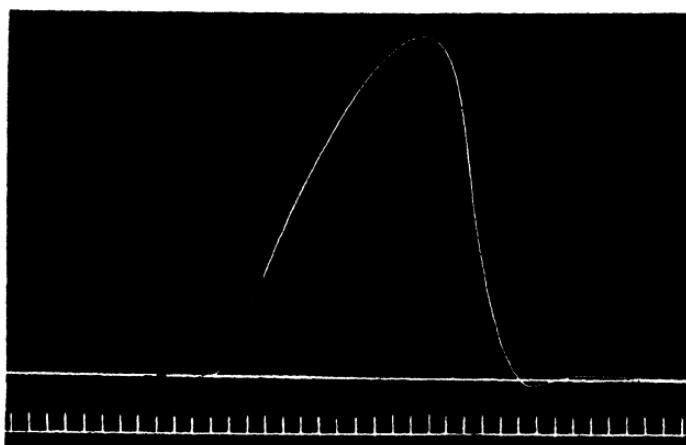


Fig. 51.—A simple Muscle Twitch of the Gastrocnemius of a Frog—stimulated via its Nerve.

The short line represents the moment at which the stimulus was applied. Note the latent period before the contraction begins. The time marker represents 0·01".

(c) Heat is produced by the chemical changes accompanying the contraction.

(d) Contracted muscle is more extensible than uncontracted.

(e) Electrical changes—active muscle becomes negative to resting muscle.

2. **Chemical Changes.**—During contraction the glycogen content of muscle is converted to lactic acid and hexose, and the phosphagen to creatin and phosphoric acid. Part of the lactic acid is oxidised to CO_2 and H_2O , while the rest is reconverted to glycogen during the period of recovery; hence we have increased oxygen consumption and CO_2 output as the result of muscular contraction.

AMOEBOID MOVEMENT is that which is seen when observing the behaviour of certain small unicellular organisms, known as amœbae. Each cell throws out irregular projections called **pseudopodia** (=false feet) accompanied by a retraction of the cell in other directions. By such means it can change its position, and can even include (ingest) between two pseudopodia small particles of nutritive material. If a drop of water from a stagnant pond be examined under the microscope these creatures may be readily seen and their movements observed.

Certain of the white corpuscles of the blood known as **polynuclear leucocytes** behave in this way. If the blood is slightly warmed their activity is increased, and if cooled they

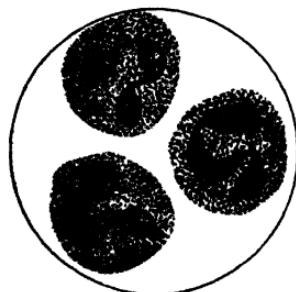


Fig. 52.—Three Phagocytes (Polymorphonuclear Leucocytes) showing Ingested Bacteria. ($\times 1500$.)

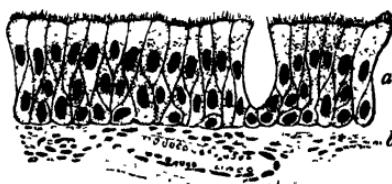


Fig. 53.—Ciliated Epithelium from the Trachea of a Kitten. ($\times 255$.)
a, columnar ciliated epithelium; b, corium.
Note the goblet cell full of mucus.

will be decreased, or even stopped. Like the amœbae they can assimilate particles, especially bacteria. In this way they are of great service to us. For instance, they wander (migrate) to a wound and dispose of foreign material that may have found its way there, and also attack bacteria that are almost certain to be present. Their behaviour in this respect is known as **phagocytosis** (Gr. *phagein*, to eat; *kutos*, a cell).

CILIARY MOVEMENT.—Fig. 53 is a picture of ciliated epithelium. During life these cilia are in constant vibratory motion of a rather peculiar kind. Each cilium bends over in the forward direction rather quickly, then there is a slow relaxation, the cilium becoming straight. This process is repeated at a rapid rate, and, moreover, the motion of succeeding cilia is in

orderly succession. By this means the cilia are enabled to give a one-way movement to the fluid (mucus, spermatozoa, or ova) which lies over them.

Ciliary motion may be conveniently observed in the frog by taking a scraping from its palatine mucous membrane, or by tearing off a portion of the gills of a mollusc (oyster or mussel). Mount it in 0·6 per cent. saline, and examine under the microscope. The activity is inherent in the cells themselves, and does not depend in any way on a connection with the nervous system. Oxygen is required for the process. It is also easy to demonstrate the action of drugs on cilia. Raising the temperature increases their rate of movement, and lowering it decreases the rate. The cause of the movement is quite unknown, though it must be dependent in some way on the cell itself, for if the latter is detached the motion ceases.

In the human body ciliated epithelium is met with :—

(a) In the air passages (trachea, and bronchi). The motion is always adoral, so that mucus plus entangled dust may be continually removed to the exterior.

(b) In the oviducts and uterus, perhaps to assist the ova to move downwards.

(c) In the epididymis to help convey the spermatozoa to the exterior, *via* the urethra.

(d) In the lining of the cerebral ventricles and central canal of the spinal cord for the circulation of the cerebro-spinal fluid.

SUMMARY

VARIETIES OF MOVEMENT.

1. **Muscular**—primary effect is production of increased tension.
Contraction (approximation of ends), therefore movement.
Nature of contraction—varies with type of muscle and arrangement of fibres. May be slow, jerky, rhythmic, peristaltic.
Physical effects—alteration of form, work done.
electrical effects, heat produced.
Chemical effects—glycogen and phosphagen decomposed.
2. **Amœboid**—pseudopodial, a primitive type of locomotion.
Phagocytosis is same process used for ingestion of food.
3. **Ciliary**—organised movement of cilia producing one-way traffic.
Where found—air passages—for dust particles *via* mucus.
genital passages—for ova, spermatozoa.
cavities of brain and cord—for flow of C.S.F.

CHAPTER VIII

THE MUSCULAR OR CONTRACTILE SYSTEM

By removing the skin which forms the external covering of the body, we expose to view masses of **flesh** or **muscle** identical with that which we call *lean meat*, which is really the muscle of the various animals used for food.

The **general character of muscle** may well be studied by examining a piece of beef. It is reddish in colour, but this is due to the presence of blood, which circulates through every part of it. If we steep a piece of beef for a very long time in cold water, a large proportion of the blood oozes out and tinges the water, leaving the flesh or muscle of a pale whitish colour. We notice also that it is composed of fibres. A large number of these muscular fibres, arranged side by side, and bound together by a membrane, form a **muscle**; and the various muscles of the body make up the **muscular system**.

THREE TYPES OF MUSCLE.—From the physiological point of view we may say there are three kinds of muscle, voluntary, involuntary, and cardiac.

(a) **Voluntary muscle**, being under the control of the will, is that which give us the power of voluntary motion and of locomotion; and these form the great bulk of the muscular system. They are often referred to as the **skeletal muscles**, and are controlled by the spinal nerves, and some of the cranial nerves.

(b) **Involuntary or plain muscle** is to be found distributed in the walls of blood-vessels, in the alimentary, genital and urinary systems, the iris and trachea. They are concerned in producing those movements over which the will has no control, such as the calibre of the blood-vessels, the motions of the stomach and intestines. The voluntary muscles are required to carry out sudden and forcible movements, while the involuntary muscles perform slow rhythmic movements so as to regulate the flow of the contents of the organs in which they occur. Both voluntary and involuntary muscles are composed of fibres, but there is a distinct microscopic difference in the form of the fibres, and also in other respects, as will be shown later.



Fig. 54.—Posterior view
of the Muscles of the
Right Arm.

1, deltoid; 2, triceps; 3, ex-
tensors of wrist.

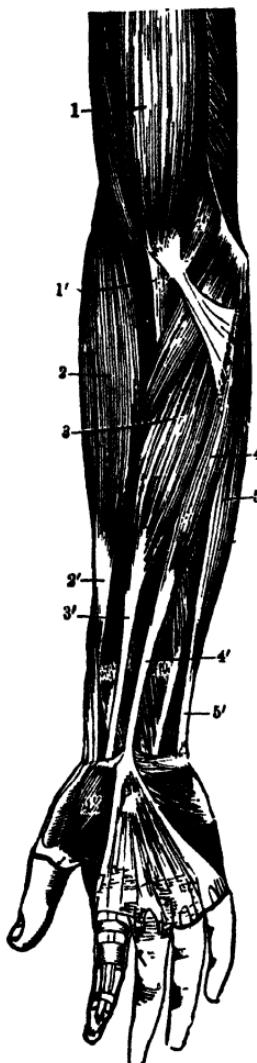


Fig. 55.—The Muscles and Tendons of the Right Forearm,
viewed from before.

1, biceps; 2, supinator longus; 3, flexor carpi radialis; 4, palmaris
longus; 5, flexor carpi ulnaris.

1' to 5', their respective tendons.

(c) **Cardiac muscle** is intermediate in character between these two types. It has certain resemblances to voluntary muscle in the strength of its contractions, and also in its microscopic appearance. On the other hand, it is like involuntary muscle in its independence of the central nervous system, and in its inherent rhythmicity.

THE VOLUNTARY OR SKELETAL MUSCLES are connected with bones at one or both ends, and every fibre composing them has the power, under the influence of the will, of contracting in length. One end of such a muscle is generally fastened by means of a **tendon** to a fixed or relatively fixed bone. This is known as the "origin." The other end is similarly attached by a tendon to the bone to be moved and is therefore the "insertion." Hence when the muscular fibres contract, the whole muscle shortens, becoming consequently thicker in the middle, and causing one of the bones to be moved.



Fig. 56.—Side view of the Muscles of the Face and Neck.

grasp the mass of flesh which forms the front of the upper arm with the right hand. Now gradually raise the left forearm, still keeping the elbow on the table, and notice how the muscle thickens as the hand rises. The chief muscle engaged in this motion is one called the **biceps muscle** (Lat. *bi*, two; and *caput*, a head), because at its upper extremity it has two heads with separate tendons. The two heads arise one from the coracoid process of the scapula, and the other from the upper margin of the glenoid cavity of the scapula; while the lower tendon is fastened to the radius, very near the elbow-joint. The points of union with the fixed bone (the scapula)

As an illustration of this, lay the left forearm on a table before you, and

are called the *points of origin* of the muscle ; the point at which the muscle is attached to the bone to be moved (the radius) is called its point of *insertion* ; and the thick, fleshy, middle part of the muscle is known as its *body* or *belly*. Some few of the muscles have no tendons, the muscular fibres being connected directly with the bone ; while others, instead of being of the form just described, are broad and flat muscular sheets. Some muscles are not connected in any way with bones.

These often enclose cavities, and are of the involuntary kind. Examples are to be seen in the heart, stomach, uterus and iris.

After a bone has been moved by a muscle it is brought back to its former position by the contraction of a second muscle on the opposite side, and also by a relaxation of the muscle which originally contracted. Hence we find that muscles are generally arranged in pairs, each muscle of a pair being antagonistic in its action to the other.

Skeletal muscles are often named according to their function :—

(1) Those muscles which are used to bend the limbs are called **flexors**. The flexor carpi ulnaris flexes (and also adducts) the wrist, while the tibialis anticus flexes the foot at the ankle joint. Those which straighten the limbs are **extensors**. The extensor carpi ulnaris extends the wrist. The calf muscles are the chief extensors of the foot at the ankle.

(2) Those which **supinate** the hand, i.e. turn it palm upwards (supinator longus), and those which **pronate** it, i.e. turn it palm downwards (pronator radii teres, pronator quadratus).

(3) Those which **adduct** a limb, i.e. draw it towards the body, e.g. the adductor pollicis longus carries the thumb towards

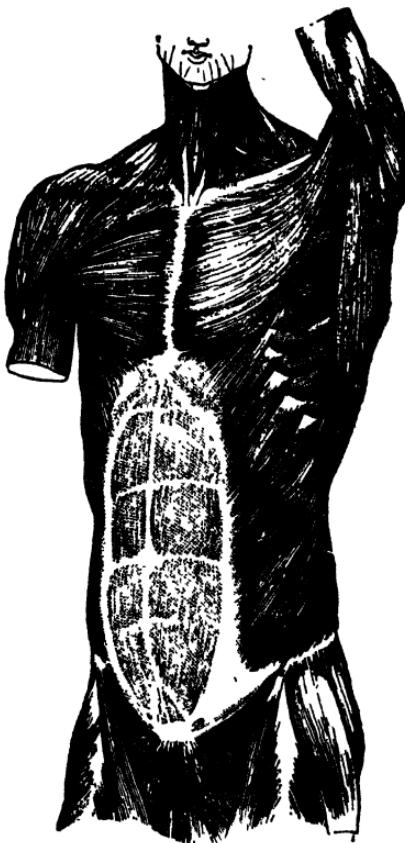


Fig. 57.—Front view of the Muscles of the Trunk.

the palm, and those which **abduct**, *i.e.* draw the limb away from the body.

(4) There are also **rotators** of limbs, both external and internal.

Thus the obturators rotate the thigh outwards, while the semitendinosus and membranosus rotate the leg inwards.

It is important to realise that the various muscles which act on a joint in the ways just described must do so in an orderly manner. Thus if the adductors are contracting, the abductors

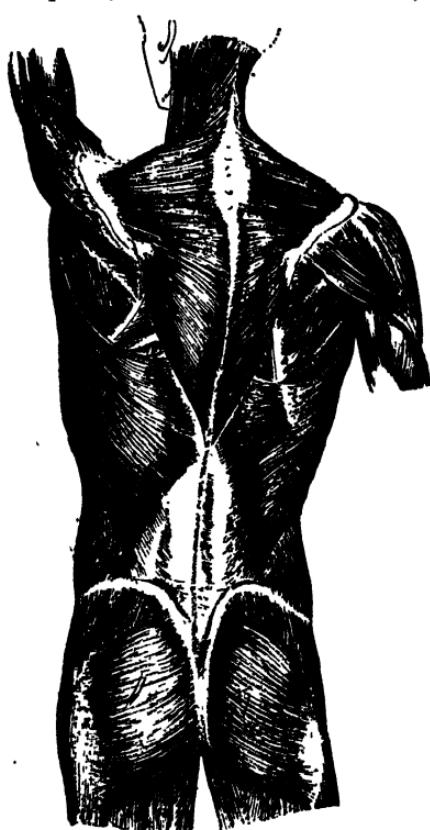


Fig. 58.—Back view of the Muscles of the Trunk.

must simultaneously be relaxing. There must be a give and take between opposing muscles. This is very well shown in fig. 60, which is a tracing taken of the simultaneous action of the hamstrings (flexors of the leg on the thigh) and the

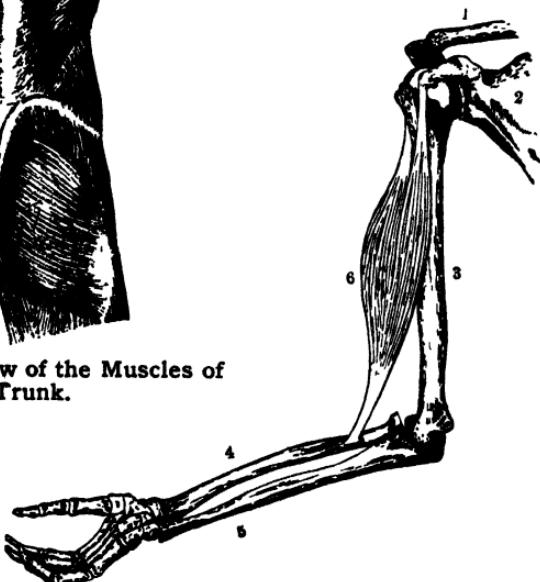


Fig. 59.—The Right Biceps Muscle.
1, clavicle; 2, scapula; 3, humerus; 4, radius; 5, ulna;
6, the biceps muscle. Note its two heads.

quadriceps (extensors of the leg on the thigh). When the latter were caused to contract (downstroke of the lever) the former group at once relaxed (upstroke of the lever).

Muscles may be made to contract by the application of some kind of stimulus which is generally conveyed to the muscular fibres by means of the nerve which distributes its branches among them. But muscular

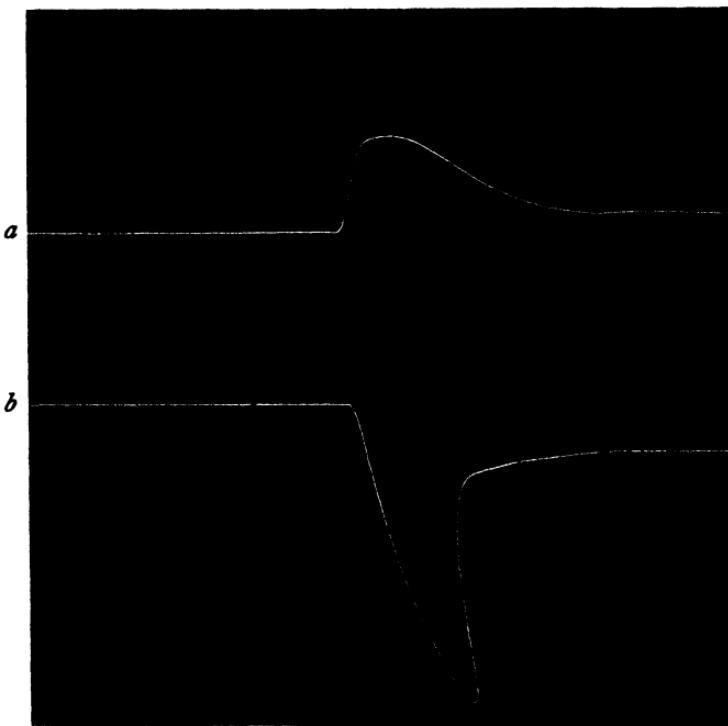


Fig. 60.—Reciprocal action between Antagonistic Muscles—flexion reflex (*Rana Esculenta*). (G. K. Taylor.)

a, flexor contraction; *b*, extensor relaxation. Note the simultaneous results.

contraction may also be produced by *mechanical irritation*, such as pinching or cutting the nerve; by *electrical irritation*, such as is produced by the electric shock; or by *chemical irritation*, such as the addition of an acid or a salt to the nerve.

Muscles may be made to respond to stimuli not only during life, but also shortly after death has occurred. Thus, the limbs of a recently killed frog may be made to jump violently by discharging a condenser through them.

Not all parts of the body die at the same time. The heart of a frog will

go on beating for many hours after its removal from the body under suitable conditions of temperature and nutrition.

RIGOR MORTIS.—Just after death, the voluntary muscles of an animal are soft and pliant as during life; but after a short time they become so stiff and hard that it is impossible to bend the limbs without a danger of injuring the bones or joints. This **death-stiffening**, or **rigor mortis**, is due to the production of lactic acid (0·5 per cent.) which causes the precipitation and opacity of the muscle protein (myosin). It is technically known as "coagulation." The muscles become shortened and stiffened, beginning at the neck and lower jaw, and gradually working downwards. It is doubtful whether rigor mortis occurs in involuntary muscle. In the human body this coagulation usually sets in at from four to six hours after death, and continues for one, two or three days. The rapidity of onset and its duration may vary greatly under different conditions. This point is often of importance in the investigation of crime. It should also be mentioned that after a varying interval of time, this rigor passes off and the muscles become softer again, due to putrefactive changes.

THE ERECT POSITION OF THE HUMAN BODY is maintained by the combined influence of a large number of muscles acting at the same time. The whole weight of the body rests on the arches of the feet; and the body may be supported in any position providing its centre of gravity is situated vertically over any point in the space enclosed by the feet. On account of the large number and suppleness of the joints, the centre of gravity cannot be maintained in such a position as described above without the contraction of certain muscles which give a degree of rigidity to the body (fig. 61).

The muscles of the calf prevent the body from falling forward, but the contraction of these alone would pull the body backward, as they act on the thigh-bone, just above and behind the knee-joint. These muscles are therefore opposed by another set in front of the thigh, which connect the hip-bone above with the bones of the leg below the knee, and which, by their contraction, pull the leg straight. Then, again, these muscles tend to pull the trunk of the body forward, but they are balanced by the powerful muscles of the buttocks and back. Further, the contraction of the muscles of the back of the neck would pull the head backward, were it not for the contraction of antagonistic muscles which connect the lower part of the face with the sternum and collar-bone.

MUSCLE TONE.—Even a resting muscle has some degree of tension ; it is not fully relaxed. This is particularly true of the skeletal muscles which are concerned in the maintenance of posture, and the condition is known as **tone**. It is a reflex, and its degree and distribution depends on the position adopted, the nature of the animal, and the condition of the nervous system. Tone is lost during sleep, anaesthesia and when the nerve supply to the muscle is cut so that it has no connection with the nervous system.

If a boxer receives a “knock-out” blow (on the point of the jaw) he falls literally “all of a heap.” His limbs suddenly become flaccid and powerless. All “tone” or semi-rigidity of the limbs is now lost. His muscles are not injured, but the blow caused a “shock” to his nervous system which governs muscle tone and equilibrium or muscular co-ordination. When the shock has passed off he will regain consciousness, and with it his tone and equilibration.

WALKING.—In this action one first inclines the body forward, then raises one foot, swings the leg forward one step, and puts the foot to ground again. Now, just for a moment, the legs form with the ground an isosceles triangle, and consequently the trunk of the body is a little lower. But, before the foot reaches the ground, the contraction of the calf of the other leg raises the heel and propels the body forward. The weight of the body is thrown on the first foot, and the one behind swings forward and passes in front of the other. A forward motion is thus given to the body, which is



Fig. 61.—Diagram showing the Action of the chief Muscles which keep the Body erect.

Muscles which tend to keep the body from falling forward.

1, muscles of the calf; 2, of the back of the thigh; 3, of the spinal column.

Muscles which tend to keep the body from falling forward.

1', muscles of the front of the leg; 2', of the front of the thigh; 3', of the front of the abdomen; 4', of the front of the neck.

The arrows indicate the direction in which these muscles act.

maintained without the expenditure of much muscular force. It will be observed that both feet are never off the ground at the same time in walking ; also that, as the forward motion of each leg is a *swinging* motion, it follows the law of pendulum motion—the longer the pendulum the more slowly it swings. Hence the natural step of a child is quicker than that of a man.

Running differs from walking in that the heels are never brought to the ground, and both feet are off the ground at the same time for a brief period at each stride. The contraction of the muscles is also much more powerful and rapid, and, in addition, the sudden straightening of the legs, by the contraction of the extensor muscles of the thighs, adds greatly to the force with which the body is propelled forward.

Jumping resembles running, as far as the action of individual muscles is concerned, but both legs act simultaneously instead of alternately, so that the body is thrown forward to a greater distance.

INVOLUNTARY MUSCLE has the following characters :

- (1) It is controlled by the autonomic nervous system.
- (2) It possesses the power of inherent **rhythmicity**, well seen in the case of the isolated heart or gut of any animal.
- (3) When arranged as a tube involuntary muscle shows wave-like onward movements known as **peristalsis**.
- (4) The contractions are relatively sluggish and long sustained
a condition known as tonus.

SUMMARY

THE MUSCULAR SYSTEM—for all varieties of movement.

1. **Types of muscle**—based on histological differences :—
 - a. Voluntary or skeletal—limb movements (is rapid).
 - b. Plain or involuntary—for visceral movement (peristalsis, etc.).
Is slow, automatic and rhythmic.
 - c. Cardiac—inherently rhythmic.
2. **Types of movement**—to meet various requirements :—
 - a. Rhythmic and automatic—heart, uterus, gut.
 - b. Movement of limbs—in antagonistic groups :—
Flexors and extensors ; pronators and supinators.
Adductors and abductors ; internal and external rotators.
 - c. Movement of organs—vocal cords, eyeballs, tongue.
3. **Rigor mortis**—post mortem stiffening of muscles.
Due to coagulation of muscle proteins by lactic acid.

CHAPTER IX

BIOPHYSICS

BIOPHYSICS is the study of physical phenomena exhibited by living organisms. Some of the better known are :—

1. **VISCOSITY**.—Liquids differ in their ability to flow, due to the friction between their particles, and not with the sides of the containing vessel. It is therefore of the nature of an internal friction. **Viscosity** is defined as that property of a liquid whereby it resists relative motion of its parts. Fluid flow through a narrow pipe is slower and requires more pressure from behind to force it along than through one of wider diameter. The great resistance to flow which the heart has to overcome lies in the arteriole resistance, which raises the blood-pressure. An exaggerated condition is known as **hyperpiesis**, common in certain diseases of the kidneys (nephritis). Blood is thicker than water, as much as five times as viscous at body temperature (36° C.). The increased viscosity is mainly due to the corpuscles.

The difference in calibre between the smallest arterioles and dilated capillaries is not great. It would appear therefore that the capillaries should offer greater resistance to flow than the arterioles. This is avoided by the provision of an immense capillary bed (in total cross-section) and yet of short length (average is 0.5 mm.) as compared with that of the arterioles. Dilated capillaries, as in wound shock, result in a fall of blood-pressure, and conversely capillary constriction, brought about by injection of extract of the posterior pituitary, raises it.

2. **FILTRATION** is the passage of a solution through a porous membrane due to a difference of hydrostatic pressure on the two sides of the membrane. A very good illustration is the separation of a deproteinised plasma in the glomeruli of the kidneys. One might more properly call it "ultra-filtration," since the particles kept back are smaller than can be recognised by the microscope. The membrane also plays an important part, and in the healthy state can hold back proteins, whereas when it is inflamed (nephritis) it is permeable to proteins. Presumably,

the nature of the membrane, called its permeability, must be altered. This must depend on the fact that it is alive, for there would be no alteration of permeability in a dead membrane.

The transference of fluid from capillary vessels or *vice versa* probably depends on filtration, which will vary in directional pressure according to circumstances. The capillary walls are permeable to all the plasma constituents except proteins.

3. **ELASTICITY** is that property whereby a stretched or bent body tends to recover its original shape when the straining force is removed. All parts of the body are liable to strain and pressure, particularly the muscles and bones. The pulsations of the arteries are so modified by the elastic fibres in their walls that the blood spurts tend to become converted to a continuous, though variable flow. Similarly the areolar tissue forming the submucous coat in the wall of many organs, *e.g.* gut and bladder, contains elastic fibres so that the tissue can readily alter its size and shape in conformity with the variations in the size of the organ of which it forms part.

4. **DIFFUSION** is the process whereby a soluble solid (or liquid) put into water gradually spreads itself throughout the liquid. Colloids diffuse but slowly, while non-colloids (crystalloids) spread rapidly. The term also refers to the passage of a gas through a membrane or into another gas. This spread is due to the fact that the particles composing the solute are in molecular motion. A good example is the escape of CO₂ from the pulmonary capillaries into the alveoli, and the passage of O₂ from the alveolar air into these capillaries.

5. **PERMEABILITY** is that property possessed by a membrane which allows some substances to pass through it, and not others. It must be remembered that cell membranes are living structures, and that at one moment they may allow the passage of a substance, and at another this same substance may be stopped, according to the condition of the cell. This would not be the case with a dead membrane. If all solutes are allowed to pass through the membrane is said to be "permeable," while if, as is the more usual, it allows some to pass and not others it is "semi-permeable." An impermeable membrane is, of course, one which allows nothing to pass. A semi-permeable membrane is met with in the glomeruli of the kidneys, for they allow a deproteinised plasma to permeate. Also the pulmonary alveoli allow CO₂ to pass out from the pulmonary capillaries into the alveoli, and O₂ to pass into the blood from the air in the alveoli.

6. **SURFACE EFFECTS** are shown wherever there is an interface between two liquids, or a solid and liquid. This leads to the production of various phenomena, such as surface tension, osmotic pressure, and adsorption.

(a) **Surface Tension**.—Liquids behave as if their surface was under tension. Drops of oil in water, or globules of mercury on a plate, act as if they were enclosed by their stretched surface. Water surfaces tend to shrink so that there is the smallest surface for a given volume. Anything dissolved in water lowers its surface tension, especially soaps and bile salts. Hence fat globules become broken up into smaller ones. This is of value, for by so doing more surface is exposed to the action of the enzyme lipase which hydrolyses (splits up) the fat to fatty acid and glycerol, thus rendering the fat fit for absorption into the blood and lymphatics.

(b) **Adsorption** is the tendency for substances in solution (solutes) to accumulate at the surface of contact with the air or other liquid. Examples are seen in the fat droplets of milk. Adjacent drops will not coalesce because each is surrounded by an adsorbed layer of protein. Similarly, proteins adsorb dyes, carbohydrates, fats and even each other. Certain insoluble powders adsorb the poisons produced by bacteria (called toxins). Charcoal, cellulose and kaolin are examples. Hence these substances are useful for intestinal infections. A suspension of kaolin in water is used in the treatment of Asiatic cholera and persistent diarrhoea. **Colloids** are soluble molecules of large size. Hence because of their large surface they show adsorption to a marked degree.

(c) **Osmosis** is a pressure effect shown at membranous partitions between solutions of different concentrations. It may also be regarded as a particular aspect of diffusion whereby water passes from one side to another of a membrane semi-permeable to some particular solute which is in different strengths on each side. The tendency of water molecules is to pass freely from side to side, but more pass from the side of weaker to the one of greater strength (concentration) until the two become equal. This passage of water across the membrane sets up a pressure since more are crowding in than going out, which pressure is known as osmotic pressure. The whole phenomenon is called "osmosis" (Gr. *osmos*, a push). This pressure may be quite a high one, especially in plants, and is the reason for the rigidity of turgor found even in the tiniest of stalks. With animal cells whose walls are relatively fragile there can be little

turgor. Any great difference in the concentrations of the components of the adjacent cells might result in the bursting of a cell by the admission of too much water, or conversely, the cell might shrink by losing too much water. Therefore in the case of animal cells the fluid in which they are bathed must be of the same osmotic pressure and therefore of the same strength. Such solutions are said to be "isotonic." For example, a 0·9 per cent. solution of NaCl is isotonic with mammalian tissue fluids.

Hæmolysis.—If water is gradually added to blood the red corpuscles swell up, become spherical in shape, and eventually burst. The contained hæmoglobin is set free, and dissolves in the plasma. The cells are said to be hæmolysed, and the swelling is due to the inward diffusion (osmosis) of water particles into the cells. There are many other ways of bringing about hæmolysis—by snake venoms, bile salts. Physiological saline is an artificial substitute for plasma, with which it agrees in its percentage composition, except that it contains no proteins.

7. THE LEVER MECHANICS and the principle upon which it works is probably well known to all. It is interesting to note what great use is made in the body of this mechanical aid. This is especially shown in the case of the long bones with their muscular attachments. Thus we have :—

Levers of the first class.—Here the fulcrum lies between the effort and the load. As illustrations we have the head rocking on the atlas making nodding movements (fig. 62), and also by the toes pressing on the ground, the heel being raised.

(1) **The head rocking on the atlas.**—The fulcrum is formed by those parts of the atlas that support the condyles of the occipital bone (see page 23). When the muscles of the back of the neck contract, the face is raised. When the antagonistic muscles in the front of the neck contract, the back of the head is raised. So that the face and the back of the head alternately represent the power and the weight.

(2) **Lift one foot,** and then, by tapping the toe on the ground, we use the foot as a lever of the first order. In this case the power is applied behind by the contraction of the muscles of the calf, the fulcrum is at the ankle, and the ground offers the resistance.

(3) **The motion of the body on the hip** is another illustration. The hip-joints form the fulcrum, *i.e.* the heads of the femora; and the contraction of the muscles connecting the back of the pelvis with the bones of the leg provide the power. In this case the power (and the weight) may be alternately in

front and behind. Omitting the lower limbs we may consider that the centre of gravity lies in the thorax.

Levers of the second class have the weight situated between the fulcrum and power. Examples are :—

(1) **The lifting of one leg off the ground.**—In this case the hip-joint is the fulcrum, the leg is the weight to be moved, and the lifting power is produced by the contraction of the extensor muscles of the front of the thigh, which reach from the hip-bone to the knee-cap.

(2) **Raising the body on the toe.**—The toe rests on the ground, thus forming the fulcrum. The weight is that of the body supported at the ankle, and the power is supplied by

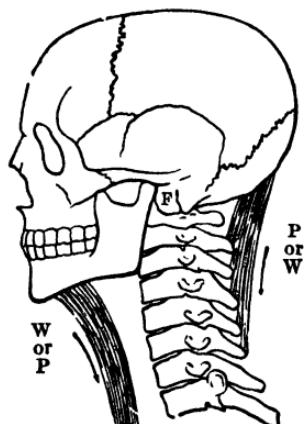


Fig. 62.—The Head rock-
ing on the Atlas.

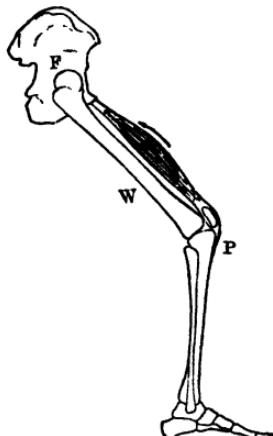


Fig. 63.—Lifting the Leg
off the Ground.

w, weight; p, power; f, fulcrum.

the contraction of the muscles of the calf, which are inserted into the heel. Note the use of this in walking, for the entire weight of the body has to be counterbalanced by the pull of the calf muscles, here acting at great mechanical advantage.

Levers of the third class are illustrated by the flexion of the forearm, the extension of the leg after bending, and the lifting of a weight by the toes without raising the leg.

(1) **Raising or flexion of the forearm.**—Here the elbow-joint forms the fulcrum, the forearm and hand the weight to be raised, and the power, which is supplied by the contraction of the biceps muscle, is applied at the upper end of the radius (fig. 64).

(2) **The extension of the leg after bending.**—The knee-joint is the fulcrum, the lower leg and the foot the weight to be moved, and the power is applied at the tibia in front of the leg, by means of muscles passing from it, over the knee-cap, to the hip.

Notice that in these two cases the muscles are acting at a

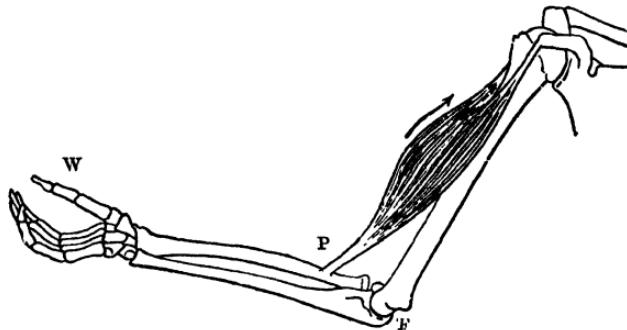


Fig. 64.—Raising or flexing the Forearm.

F, is fulcrum; P, power; W, weight (something held in hand).

great mechanical disadvantage, the power exerted being much greater than that of the weight moved. So that here nature has discarded advantage for the sake of compactness of architecture.

The great majority of the levers found in the body are of the third class, *i.e.* the muscles are acting at great mechanical

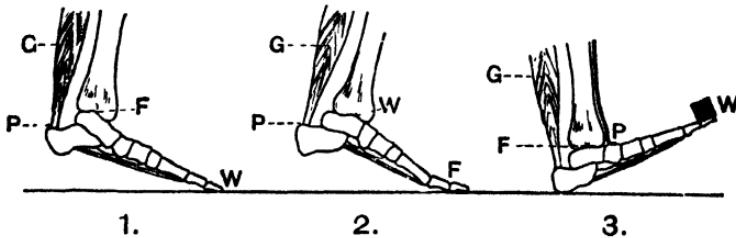


Fig. 65.—Illustrating the three Types of Levers by movements at the Ankle.

1, tapping the floor; 2, rising on the toe; 3, lifting a weight by the toes.
F, fulcrum; P, power; W, weight; G, is the gastrocnemius muscle.

disadvantage for the force exerted is much greater than the weight moved. In these cases it seems as if there was a sacrifice of muscular strength to gain compactness of design. There are not many examples of the second class, though they have great mechanical advantage. Those of the first class have the

weight arm longer than the power arm, so that they, too, act at a mechanical disadvantage. In these cases it will be found that this disadvantage is overpowered by the necessity for great rapidity and wide sweep of movement at the far end of the lever —*e.g.* the fist in boxing.

The student should think out other examples of lever action. To this end he might with advantage consider the motions of the lower jaw, the ribs, and other movements of the limbs, such as rotation, adduction and abduction.

Other instances of physical phenomena may be noted, such as the luminous organs of many insects and fishes, and the electric organs of certain clasmobranchs and teleosts.

SUMMARY

1. **Viscosity**—resistance to flow by the relative parts of a liquid.
Main resistance to blood flow is in the arterioles—raises B.P.
Hence the advantage of control over their variations in calibre.
2. **Filtration**—passage of liquid through a membrane due to difference of pressure on each side—as in the glomeruli and exudation of lymph.
3. **Elasticity**—power to recover original size and shape after stretching.
Shown by bones, arteries and areolar tissue.
4. **Diffusion**—spread of a solute through a solvent by its own molecular motion, until concentration is uniform.
5. **Permeability**—the ability of a membrane to allow the passage of a substance through it. Distinct from filtration.
6. **Surface effects**—due to interface action (solid-liquid, or liquid-liquid).
 - a. Surface tension—fat globules are spherical.
 - b. Adsorption—accumulation of solute at a surface.
 - c. Osmosis—excess passage water molecules through a membrane, on each side of which is a solute of different strengths.
7. **Mechanical principle of the lever.**
 - a. First order—those in body act at a mechanical disadvantage due to necessity for wide sweep of movement and rapidity of action, *e.g.* rocking of head on atlas; bending body at hip.
 - b. Second order—few examples, though they act advantageously, *e.g.* lifting the leg off the ground; raising the body on toes.
 - c. Third order—most of the joint movements are of this class. They all act at a disadvantage, *e.g.* flexion of the forearm; extension of the leg.

CHAPTER X

THE CŒLOM, THORAX AND ABDOMEN

THE CŒLOM.—On opening the lower part of the body of a vertebrate animal we come upon a (potential) cavity behind the walls of organs, such as the liver, stomach, pancreas, etc. It is known as the **Cœlom** (Gr. *koiloma*, a cavity), and is found in many other creatures than the vertebrates, such as

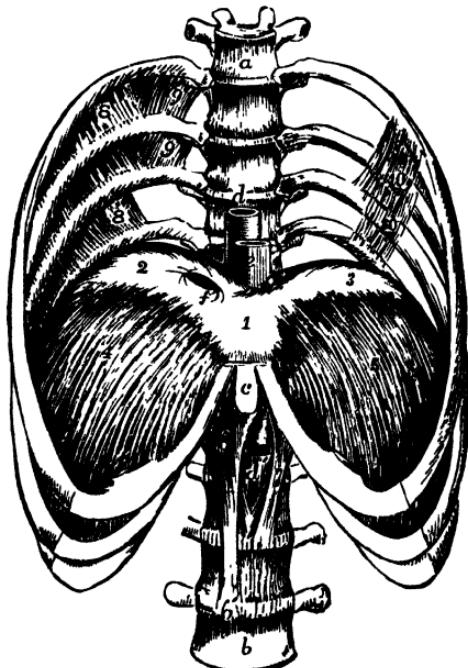


Fig. 66.—The Diaphragm, etc.

a, sixth dorsal vertebra ; **b**, fourth lumbar vertebra ; **c**, lower cartilaginous extremity of the breast-bone (xiphoid process) ; **d d'**, a great blood-vessel (aorta) passing through the diaphragm ; **e**, oesophagus ; **f**, opening through which a great vein (inferior vena cava) passes ; **1**, **2** and **3**, tendinous portion of the diaphragm ; **4** and **5**, muscular portion of the diaphragm ; **6** and **7**, the pillars of the diaphragm. These are powerful tendons which connect the diaphragm with the spinal column. **8**, **9** and **10**, intercostal muscles

the earthworm and the oyster. On careful examination it will be seen that the upper and lower portions of the trunk are separated by a partition. This is an arched musculo-tendinous structure, the **diaphragm** (Gr. *dia*, through; *phragma*, a fence) or **midriff**. The upper portion is called the **Thorax** (Gr. a *breast plate*) and the lower the **Abdomen** (Lat. *abdo*, I hide). On still closer inspection it will be found that the thorax has three separate cœlomic cavities, one each enclosing the lungs and known as the pleural cavities, and one enclosing the heart, called the *pericardial* cavity. It is of interest to note that the diaphragm is a structure distinctive of mammals, being a muscle primarily concerned with their particular mode of respiration.

We must now consider the general anatomy of the thorax and abdomen.

THE ABDOMEN is that part of the trunk which lies between the diaphragm and the pelvis. It is bounded above by the diaphragm, behind by the lumbar vertebrae and the psoas and quadratus lumborum muscles. At the sides it is bounded by the ilia and parts of the transversalis and oblique muscles. In front are these same muscles, together with the two recti.

On opening the abdomen the following structures can be seen without any disturbance of the viscera:—

Just under the right ribs and costal cartilages is the liver, which extends across to the other side, while below it and to its left is the anterior surface of the stomach. Stretching downwards from this organ is a double fold of peritoneum, known as the omentum (Lat. *omentum*, the caul), behind which is the transverse colon, while all around are seen coils of the small intestine. Low down in the right-hand corner or fossa is the cæcum, and in the left-hand fossa is the iliac colon. To the left of and behind the stomach under the left lower ribs is the lower border of the spleen, and appearing just below the edge of the liver is the gall bladder. Above the upper border of the pubic bone (the *symphysis pubis*) in the midline may be seen the upper surface of the urinary bladder.

THE CONTENTS OF THE ABDOMEN are briefly:—

1. The greater part of the alimentary canal together with the digestive glands, the liver and the pancreas.
2. The urinary apparatus—kidneys, ureters and bladder.
3. The spleen and the suprarenals.
4. Blood and lymph vessels and lymphatic glands.

5. The abdominal portions of the spinal and autonomic nerves.

6. The peritoneum, with its folds—omenta and mesenteries.

PERITONEUM.—The walls and organs of abdomen are lined with a smooth, thin, glistening membrane, of flattened endothelium, the **peritoneum** (Gr. *peri*, around; *teino*, I

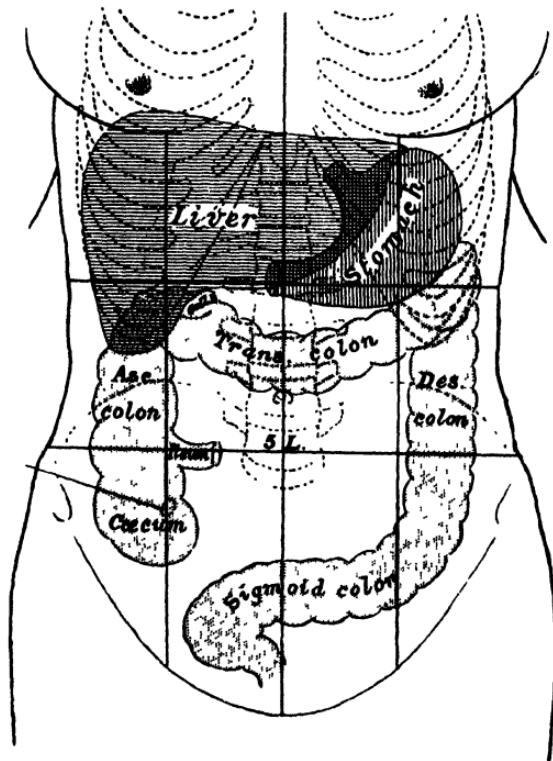


Fig. 67.—Front of Abdomen, showing the Surface Markings for the Liver, Stomach, Gall Bladder and large Intestine.

stretch). If we trace this (parietal) peritoneum around to the back it will be found folded ventrally on each side of the vertebral column. The two folds come together and enclose between them the various abdominal organs. The latter are therefore suspended as it were from the dorsal wall and project into the coelomic cavity. The peritoneal folds which enclose the viscera

are called the visceral peritoneum or **mesenteries** (Gr. *mesos*, middle; *enteron*, the intestine). There are also special peritoneal folds connecting liver and stomach (lesser omentum) and stomach with transverse colon (greater omentum). It therefore comes about that there are not really any organs actually within the cœlomic cavity, they are all extraperitoneal. The cavity moreover is only a potential one in the sense that parietal and visceral layers are in contact with each other, and

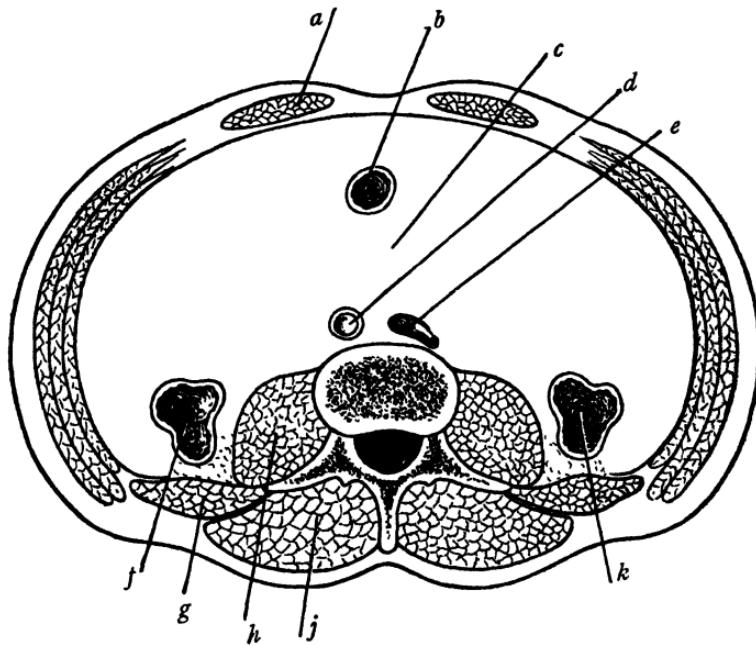


Fig. 68.—Transverse Section of the Lower Abdomen, to show the arrangement of the Peritoneum.

a, rectus; **b**, small intestine; **c**, mesentery; **d**, aorta; **e**, inf. vena cava; **f**, descending colon; **g**, quadratus lumborum; **h**, psoas; **j**, spinalis; **k**, ascending colon.

only separated by a very small quantity of serous fluid. This fluid serves to lubricate the folds so that the various organs may glide and rub against each other freely. It also carries the blood-vessels, nerves and lymphatics concerned with the activity of the organs. The peritoneal cavity is a completely closed sac in the male, but in the female there are two small apertures, one each side, in the lower part of the abdominal cavity which lead into the oviducts.

APERTURES IN THE ABDOMINAL WALL.—There are certain openings in the abdominal cavity for the passage of structures to and from it :—

1. Diaphragmatic openings—for the aorta, inferior vena cava, thoracic duct, oesophagus and vagi.
2. In the pelvic floor—for the rectum and urethra in both sexes, and vagina in the female.
3. The inguinal canal—for the spermatic cord in the male, and the round ligament of the uterus in the female.
4. The crural canal—for the femoral blood-vessels.
5. In the foetus there is an opening (the umbilicus) in the front of the abdomen for the transmission of the umbilical arteries from the foetus to the placenta ; the umbilical vein to the liver from the placenta ; the vitelline duct and the allantois.

HERNIAE (OR RUPTURES).—While considering the various abdominal apertures it is of some interest to realise that, due to the existence of these potential openings, often imperfectly closed, there is always the possibility that some portion of the gut, being so freely movable, can gradually slide down into one or other of these apertures (pushing the parietal peritoneum in front of it) and so produce what is called a rupture or a hernia (Lat. *hernia*, a protrusion). Three common ones are :—

(a) Inguinal—where the gut pushes its way down the inguinal canal, along the front of the spermatic cord, and eventually descends into the scrotum in the male or labium in the female.

The inguinal canal is situated at the inner side of the groin, and contains the spermatic cord in the male, and the round ligament of the uterus, in the female.

(b) Femoral—the gut protrudes through the crural canal (femoral ring), a potential opening at the inner side of the groin, internal to the femoral vessels, and just under Poupart's ligament.

(c) Umbilical—the hernia enters through a stretched umbilical scar or cicatrix. It is common in young babies and cretins.

Other varieties of hernia occur.

THE DIAPHRAGM is a muscular septum which divides the thoracic from the abdominal cavity. It has three large openings, already mentioned. Its upper surface lies against the pleuræ and pericardium, while the under surface touches the kidneys, suprarenals, liver, stomach and spleen. The diaphragm is one of the most important muscles of respiration. It is supplied by the phrenic nerve which is derived from the 3-5 cervical nerves. Some fibres are motor and others sensory.

THE PELVIS is the lower portion of the abdominal cavity. It is bounded behind by the sacrum (covered by the pyriformis muscle) and the coccyx ; in front by the pubes ; at

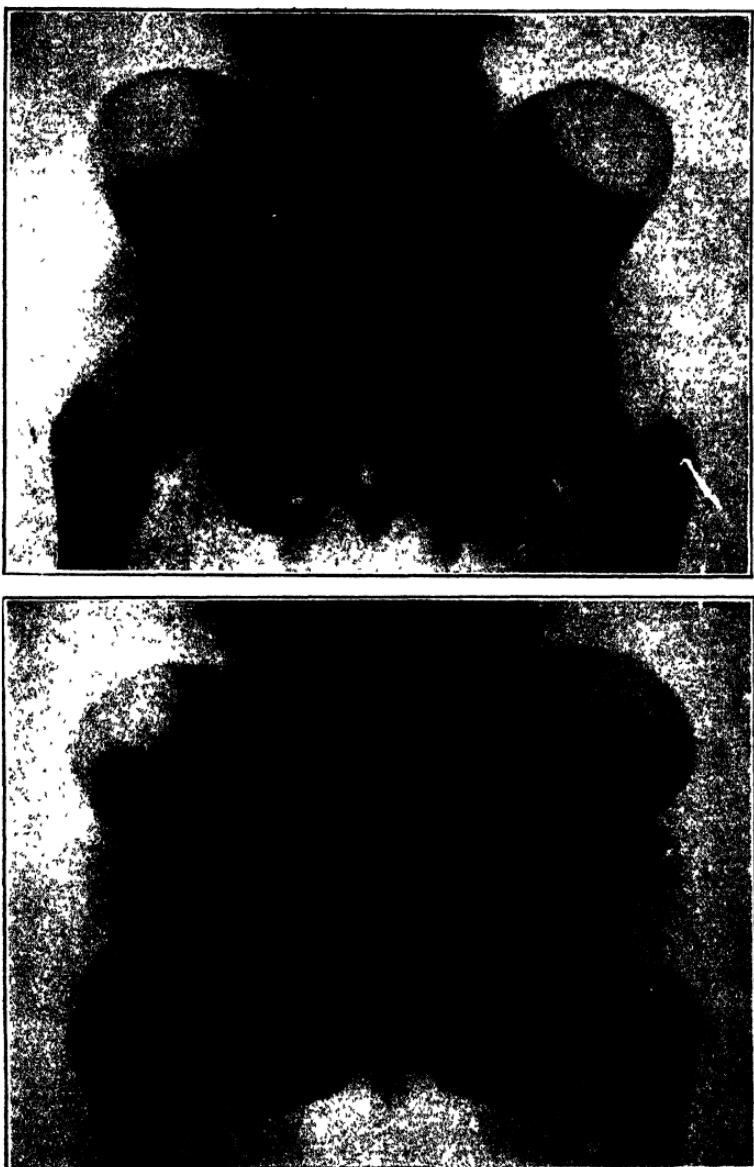


Fig. 69.—Radiogram of the pelvis of a boy of ten (above) and a girl of eleven (below), showing the marked differences before puberty. The girl's pelvis is already wider than that of the boy's, and the femurs are set at different angles.

the sides by the ischia covered by the obturator muscles ; above by the abdomen proper ; and the floor is formed by the levatores ani and coccygeal muscles.

It contains the sigmoid colon, rectum, urinary bladder and a few coils of the small intestine. In the male are the prostate, seminal vesicles, and vas deferens ; while in the female are the ovaries, oviducts, uterus and vagina.

The marked differences in the size and shape of the male and female pelvis have already been described. They are of importance in midwifery, and in determining the sex of a skeleton.

THE THORAX OR CHEST is the upper part of the trunk lying between the fore limbs (arms) and above the diaphragm, as already mentioned. Its bony and cartilaginous skeleton has been described in Chap. V. The thorax is of conical shape, flattened from before backwards, and is lower behind than in front.

The boundaries of the thorax are :—The diaphragm below, the twelve thoracic vertebræ with the posterior parts of the adjacent ribs behind, the sternum and costal cartilages in front, while the ribs and intercostal muscles lie laterally.

The contents of the thorax are :—

- (a) The trachea, right and left bronchi, and the bronchioles.
- (b) The lungs and their pleuræ.
- (c) The œsophagus.
- (d) The heart with its pericardium and great blood-vessels—the aorta pulmonary vessels, and the venæ cavæ.
- (e) The thoracic duct.

Cœlomic cavities—the thorax contains three, the pericardial and two pleural. The heart and lungs, like the gut, do not lie within the cœlom, but are entirely outside it.

Sex differences.—It is of interest to notice that there are certain differences in the thorax in the two sexes. The female thorax is of less capacity than the male, the sternum and clavicle are shorter, and the upper ribs are more movable. This affects the “vital capacity” (see Chap. XXVI).

SUMMARY

THE THORAX—is the upper portion of the trunk.

Walls	{ Back—the 12 thoracic vertebrae. Front—sternum, costal cartilages. Floor—diaphragm. Sides—ribs, intercostal muscles.
Contents	{ Trachea, bronchi, bronchioles, lungs, pleuræ. Esophagus, thoracic duct.
Sex differences	Heart, pericardium, great blood-vessels. Female thorax less capacity, sternum and clavicle shorter, upper ribs more movable than in male.

THE DIAPHRAGM—musculo membranous partition dividing thorax and abdomen. Supplied by the phrenic nerve (3–5 C.).

Above it—pleuræ, pericardium.
Below it—liver, stomach, kidneys, suprarenals, spleen.
Through it—aorta, œsophagus, inferior vena cava.

THE ABDOMEN—the lower portion of the trunk, walls and organs lined by peritoneum.

a. Abdomen proper.

Walls	{ Roof—diaphragm. Back—vertebral column. Sides and front—abdominal muscles.
Contents	Liver, pancreas, spleen, kidneys, stomach, gut.

b. Pelvis.

Walls	{ Sides—the pelvic bones. Floor—muscles (Levator ani, coccygeus).
Contents	Urinary bladder (partly), some coils of gut. ♂ Prostate, vas deferens, vesiculæ seminales. ♀ Ovaries, oviducts, uterus, vagina.

CHAPTER XI

THE ANATOMY OF THE FACE AND NECK

IT will be advisable to study the anatomy of the face and neck before learning the nature of the organs contained in the thorax and abdomen, as by adopting this plan we shall be able to understand better the connection between them and the organs of the face.

The accompanying diagram exhibits a medial section of the face and neck, that is, a section carried from the tip of the nose backward, thus cutting through the middle of the cervical portion of the vertebral column.

BONES OF THE FACE.—We first proceed to note the positions of the chief bones of the face, etc., as exposed in this section.

The **sphenoid bone** separates the upper and back portion of the cavity of the nose from the cavity of the skull.

The **ethmoid bone** separates the same two cavities more toward the front, *i.e.* anteriorly.

The **nasal bones** form the upper and hard portion of the ridge of the nose, the lower portion of which is constructed of cartilage and is therefore flexible.

The cavity of the nose is limited below by the **superior maxillary bones** and the **palatal bones** behind them ; these forming together the **hard palate**. The roof is formed mainly by the nasal bone, and the cribriform plate of the ethmoid.

It will thus be seen that the **nasal cavity** occupies a very large proportion of the face. It is divided centrally from front to back by a very thin bony plate, the **vomer**, and its outer or right and left walls are formed by the **superior and middle turbinated processes** which form part of the ethmoid bone. There is also a *lower* turbinated bone, distinct from the ethmoid.

Below the nasal cavities, and separated from them by the hard palate, is the **cavity of the mouth**. The roof of the mouth is continued backward from the hard palate by the **soft palate**, which is composed of fleshy substance, without any kind of hard support. The soft palate forms an incomplete septum called the **palatine velum** between the mouth and the pharynx.

Its lower border is free and hangs down between the mouth and pharynx like a curtain. It is known as the **uvula**. On either side are two fleshy arches, an anterior and a posterior, between which is the **tonsil**. It is often the seat of inflammation—**tonsilitis**. If the infection spreads around, the condition is known as a **quinsy**.

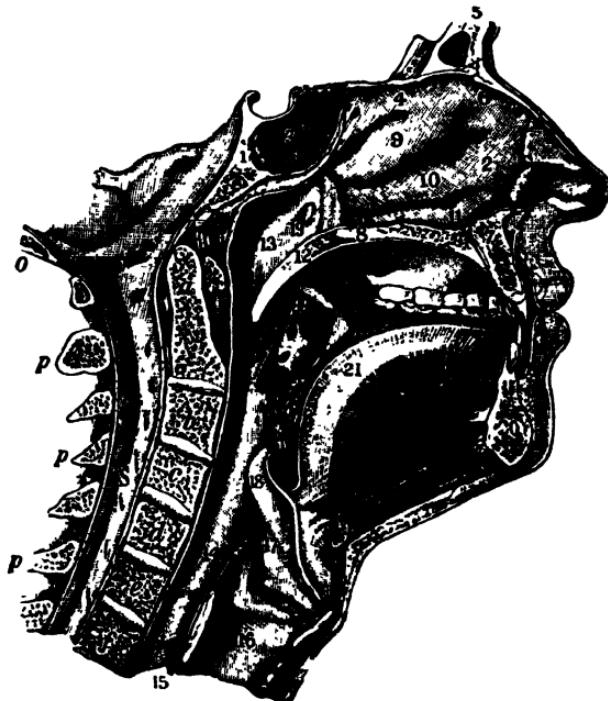


Fig. 70.—Medial Section of the Face and Neck.

1, sphenoid bone; 2, nasal cavity; 3, air sinus; 4, ethmoid bone; 5, frontal bone; 6, nasal bone; 7, superior maxillary bone; 8, palatal bone; 9, superior turbinate process; 10, middle turbinate process; 11, inferior turbinate bone; 12, soft palate; 13, upper part of pharynx; 14, lower part of pharynx; 15, oesophagus; 16, larynx; 17, glottis; 18, epiglottis; 19, opening of Eustachian tube; 20, inferior maxillary bone; 21, tongue; 22, tonsil; 23, bodies of cervical vertebrae; S, spinal cord; p, processes of cervical vertebrae; o, portion of occipital bone.

THE PHARYNX, OESOPHAGUS AND TRACHEA.

—The cavities of the mouth and nose both lead into another cavity called the **pharynx**.

It is a tube partly membranous and partly muscular, and extends from the under surface of the skull to the level of the **cricoid cartilage**, which lies just below the thyroid cartilage.

The lower part of the pharynx is continuous with a fleshy tube which leads downward from it, passing completely through the thorax and the diaphragm, and then entering the *stomach*. This tube is called the **œsophagus**, **gullet** or **food-pipe**. Thus, after food or drink has passed through the mouth, between the tongue and the palate, it enters the pharynx, and is then conveyed to the stomach by means of the œsophagus.

There is another tube that leads downward from the pharynx. It is situated just in front of the œsophagus, and is that hard tube which may be felt in the front part of the throat. This is

a cartilaginous tube called the **trachea** or **windpipe**. The upper part is larger and wider than the rest, and forms that prominence in the front of the throat, especially noticeable in the adult male, which is popularly called Adam's apple (*pomum Adami*). It is the **larynx** (Gr. *larugx*) or **voice-box**, so called because it contains the *vocal cords* by the vibration of which the voice is produced. Note that it lies between the trachea and the root of the tongue. The trachea, including the larynx, is composed of incomplete rings of *cartilage* or *gristle*, connected by means of soft *fibrous tissue*; this accounts for the irregularity or *roughness* experienced by pressing the fingers down the front of the throat.

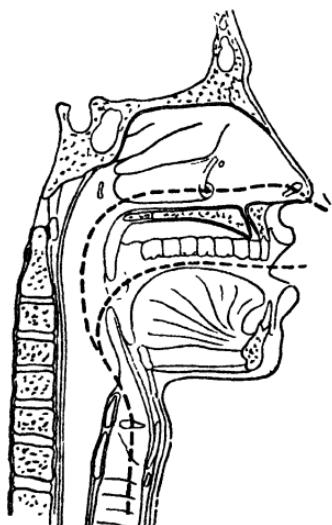


Fig. 71.—Section of the Face and Neck.

Showing the direction taken by the air during breathing, speaking, etc.

the **glottis**. It is surmounted by a cartilaginous lid known as the **epiglottis** (Gr. *epi*, upon). During breathing, speaking, etc., the glottis is open, the epiglottis being in the position shown in fig. 71; but during the act of swallowing, just at the moment when food or drink is passing the top of the larynx, the glottis is closed, thus preventing any solid or liquid matter from entering the trachea.

We may now trace the course taken by air during the act of inspiration. If the mouth is closed the air inspired passes through the nostrils or **anterior nares** and then along the

lower part of the nasal cavities. It next enters the pharynx by means of two openings called the **posterior nares**, one of which leads from each nasal cavity. The air then passes down the pharynx, through the glottis larynx, trachea and lungs.

If the mouth is open during ordinary breathing, some of the air still passes through the nose, taking the course just described. That which enters the mouth takes a shorter course, passing direct from the mouth into the pharynx ; and then, joining the former current, goes with it through the glottis, the larynx and the trachea.

The **pharynx has seven passages** communicating with it :—

The posterior nares, leading from the nasal cavities, the mouth, œsophagus, larynx, and the Eustachian tubes. The latter form communications between the nasal part of the pharynx and the tympanic cavity, of each side.

SUMMARY

STRUCTURES FORMING THE NASAL CAVITIES.

THE PHARYNX communicates with

THE PALATE

THE TONSILS

FOOD PASSAGES

AIR PASSAGES

Ethmoid bone.	Superior and middle turbinated processes. Partly separates cranial and nasal cavities, and forms outer walls of nasal cavity.
Vomer	Separates right and left nasal cavities.
Nasal bones	Upper part of bridge of nose.
Nasal cartilages	Flexible framework of nose.
Sphenoid bone	Lies between the posterior portion of the nasal cavity and the brain.
Superior maxillary bones	Form the hard palate.
Palatal bones	
Nasal cavities, by the posterior nares.	
Mouth, or oral cavity.	
Middle ear, by the Eustachian tube.	
Trachea, by the glottis.	
Œsophagus, and so with the stomach.	
Hard.	Superior maxillary and palatal bones.
Soft.	Fleshy. Forms the back portion of the roof of the mouth and the uvula.
	Between upper pharynx and mouth.
	Lie between the faucial pillars. Lymphoid tissue.
Mouth→pharynx→œsophagus→stomach→small intestine→large intestine→rectum→anus.	
1. Nostrils (anterior nares)→posterior nares→pharynx→glottis→trachea→bronchi→bronchioles→alveoli.	
2. Mouth→pharynx→glottis→trachea→etc.	

CHAPTER XII

THE ORGANS OF THE THORAX

WE have so far considered the thorax as a whole, and now proceed to study its various contents. In some cases the full discussion is left to be more fully dealt with in the relevant chapters concerned with their physiological functions.

1. **THE TRACHEA** (Gr. *trachus*, rough) or **wind pipe** is a wide tube kept open by a series of 16 to 20 cartilaginous hoops, shaped like the letter C, and arranged so as to be complete before and deficient behind. These rings are surrounded externally by fibrous connective tissue, which also joins their extremities, thus completing the tube behind ; it also fills in the spaces between the rings. Its length is about 11 cms. The trachea is a resistant and elastic tube, which, though always open for the passage of air, will yield with the bending of the neck, and will also allow of the distension of the oesophagus, which lies against its posterior portion where the cartilage is absent. It starts on a level with the sixth cervical vertebra, and reaches to the upper border of the fifth thoracic vertebra, where it divides into **two bronchi**, one for each lung.

The deficiency of the cartilage posteriorly is filled in by involuntary muscle fibres, running horizontally. This is the **trachealis** muscle, by whose contraction the lumen of the trachea is reduced, with corresponding difficulty in breathing, as occurs in an attack of **asthma**.

The two upper cartilaginous rings, which are much larger than the others, form the framework of the **larynx**. The first, called the **thyroid cartilage** (Gr. *thureos*, a shield ; *eidos*, form), is very wide in front, forming the pomum Adami, mentioned above, but is open behind, and connected by ligaments and muscles with a small U-shaped bone, the **hyoid bone** (Gr. letter *v*), situated just above it. It is the largest cartilage of the larynx, and is particularly prominent in the male. The second, or the **cricoid cartilage** (Gr. *krikos*, ring ; and *eidos*, form), is the only *complete ring* in the windpipe. It is smaller, but stronger

than the thyroid and forms the lower back part of the larynx. Its broadest portion is behind, while in front it is so narrow that a space is left between it and the first, this space being occupied

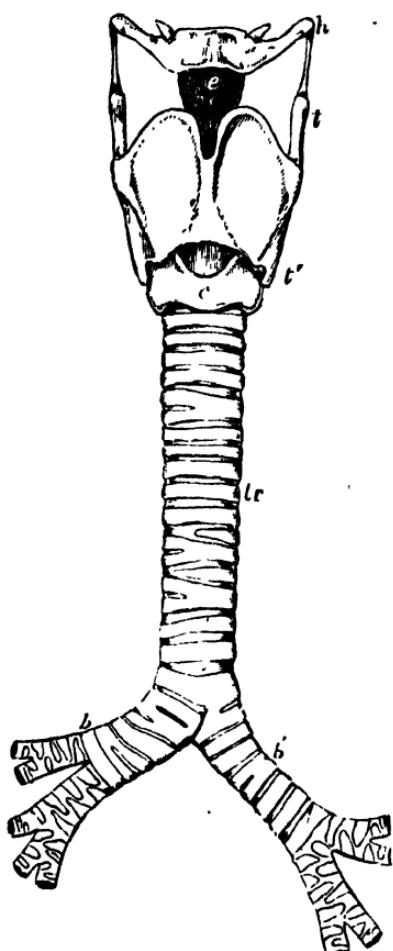


Fig. 72.—The Trachea. Anterior.

h, hyoid bone; *t'*, thyroid cartilage; *c*, cricoid; *e*, epiglottis; *tr*, trachea; *b* and *b'*, bronchi.

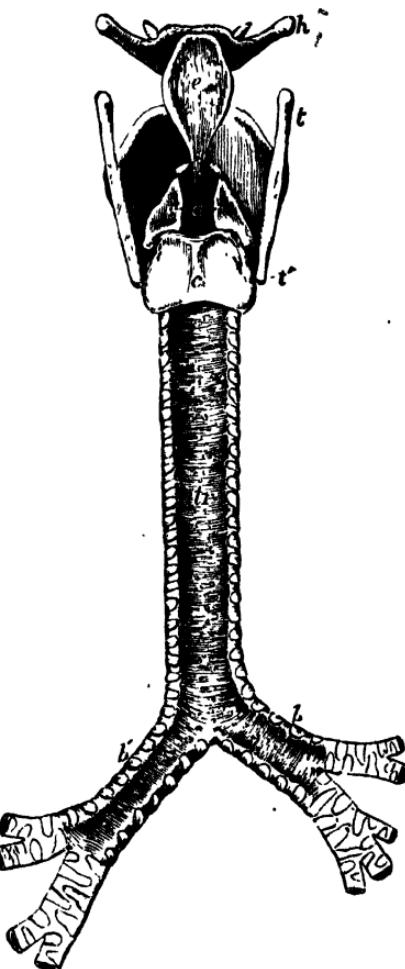


Fig. 73.—The Trachea. Posterior.

a, arytenoid cartilages; *h*, hyoid bone; *t'*, thyroid cartilage; *c*, cricoid; *e*, epiglottis; *tr*, trachea; *b* and *b'*, bronchi.

by the fibrous tissue. Of course, this second ring will not so freely admit of the distension of the oesophagus behind it, and this will account for the sharp pain we experience in the upper

part of the throat when we swallow a large and hard substance, such as a solid piece of food which has not been properly masticated.

The bronchi resemble the trachea in general structure, being composed of similar rings of cartilage and fibrous tissue. The cartilages, too, are incomplete behind. The right bronchus is more upright, wider and shorter than the left. Its length is about one inch, and it enters the right lung about opposite the fifth thoracic vertebra. It divides into three branches, one for each lobe of the right lung. The left bronchus is smaller in size, but about twice as long as the right, and enters the root of the left lung opposite the sixth thoracic vertebra, where it divides into two branches; one for each lobe.

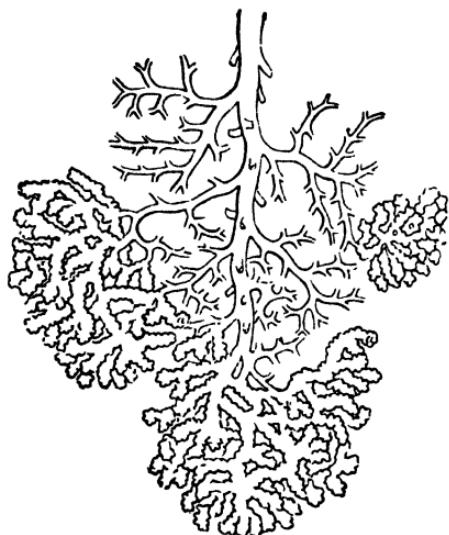


Fig. 74.—Groups of Air-cells or alveoli at the end of a Bronchiole.

The bronchi subdivide into smaller and smaller tubes, called **bronchioles**, which penetrate every part of the lungs, and end in groups of **air-cells** or **alveoli**. In the bronchial tubes the rings of cartilage are incomplete, and become more and more so as the tubes subdivide into smaller branches, until in the smallest divisions they disappear altogether. It

is in the capillaries which lie in the walls of these alveoli that the exchange of O_2 and CO_2 occurs.

The **trachea** and **bronchi** are all lined internally by a delicate **mucous membrane**, the inner surface of which is formed of a layer of columnar *ciliated cells*. The cilia, by their very rapid and continuous vibratile motion, tend to move any foreign matter which may come in contact with the inner surface of the air passages towards the mouth. This ciliary or vibratile motion is, however, a very peculiar one. The cilia make a very quick, firm, bold stroke towards the glottis, but bend on the return stroke in such a way as not to disturb the

mucus above it. Thus the latter is gradually but quite definitely urged towards the upper part of the respiratory passage. In this way the lungs are kept comparatively free from particles of dust, etc., derived from the air we breathe ; and during inflammation the phlegm discharged from the mucous membrane is always urged towards the larynx, from which it is discharged by coughing. Were it not for this provision, it is clear that we should constantly be in danger of suffocation, consequent on the accumulation of matter in the air passages. Note that there are two ways of dealing with the inhaled dust ;

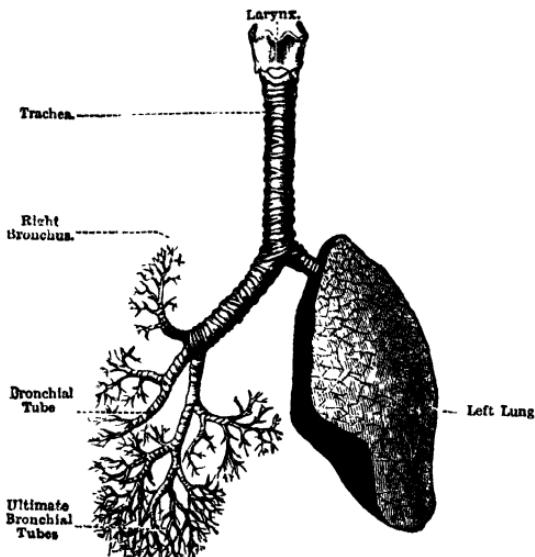


Fig. 75.—The Lungs, one being dissected to show the Air Tubes.

the particles stick to the mucus or phlegm, and there is an apparatus for its removal—swallowed or expectorated.

2. **THE LUNGS** are spongy and elastic air-bags, consisting of air-tubes and cells, blood-vessels and elastic tissue. They fill the cavity of the thorax, with the exception of the space occupied by the heart, the great vessels, and the cesophagus, consequently their general form coincides with that of this cavity. The lungs are the essential organs of respiration. They are two in number, one each side of the thorax, and separated from each other by the heart and pericardium. The lungs are of conical shape, the apices reaching just above the clavicles, and the bases resting

on the diaphragm. They are light and porous in texture, so that if a portion is placed in water it floats, or if handled it *crepitates*, i.e. makes a slight crackling sound. They are pink in colour at birth, but as age advances they get a slaty-grey colour, often very mottled, and, finally, may be almost black. This is due to the continual inhalation of sooty, dusty air. The condition is known as **anthracosis**. Before birth the lungs of course contain no air, and are not distended, a condition known as **atelectasis**.

Both right and left lungs are divided by deep depressions into **lobes**—the right into three, and the left into two. The *lobes* are

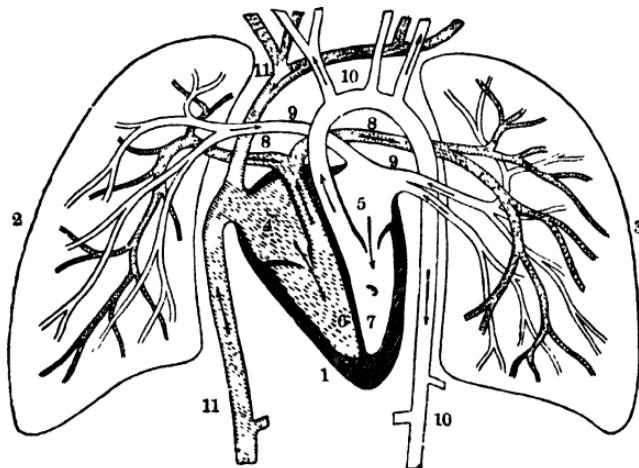


Fig. 76.—The Pulmonary Circulation.

1, heart; 2, right lung; 3, left lung; 4, right auricle; 5, left auricle; 6, right ventricle; 7, left ventricle; 8, pulmonary arteries; 9, pulmonary veins; 10, aorta; 11, venae cavae. The arrows indicate the direction of the blood-stream. The shading represents venous blood.

again divided by lesser depressions into **lobules**, each of which is a miniature representation of the whole lung, being supplied with its own system of air-tubes and blood-vessels.

The lungs are supplied with deoxygenated blood by means of the **pulmonary arteries** which proceed from the **right ventricle**. These arteries divide and subdivide into smaller and smaller branches, penetrating every portion of the organs, till at last they form **capillary networks** which surround and lie on the walls of the **air-cells**. These walls of the air-cells are extremely thin, as are also the walls of the capillary vessels, and thus the blood is brought almost in contact with the inspired

air. This is really the essential and important part of the respiratory apparatus.

It is in these capillaries that the **deoxygenated blood becomes oxygenated**, by exchanging carbonic acid gas collected in the tissues of all parts of the body for oxygen gas absorbed from the air contained in the air-cells. The total area of the surface exposed to the air is very great. The gaseous exchange which occurs here is due largely, if not entirely, to diffusion.

The blood thus changed is collected by small veins, formed by the union of the capillaries ; and these veins unite, forming larger veins, ultimately giving rise to the **pulmonary veins**, which pour their contents directly into the **left auricle**.

Apart from the consideration of respiration, the lungs themselves require nutrition. This is secured by means of the **bronchial arteries** which accompany the bronchial tubes. They are derived from the thoracic portion of the aorta. In like manner there are veins (apart from the pulmonary veins) which collect the blood so distributed to the substance of the lung. These are the **bronchial veins**.

3. **THE HEART** is a hollow muscular organ, situated nearly in the middle of the front and lower part of the chest, just above the diaphragm. It is somewhat conical in form, and is placed with its broad portion or **base** uppermost, and with its **apex** or pointed end turned downward and toward the left. The position of the apex may be determined by its pulsation. In the normal adult it lies behind the fifth left intercostal space, $3\frac{1}{2}$ inches from the mid line. The size of the heart is about equal to that of the closed fist, and in the adult it weighs about 9 to 11 ounces. The mammalian heart contains **four cavities** through which the blood circulates ; and by its powerful contractions it forces this fluid through all the blood-vessels of the body.

It is characteristic of all vertebrates, that the heart is situated ventral to the alimentary canal. Further details will be more conveniently studied later on.

4. **THE GREAT BLOOD-VESSELS** which are connected with the heart. These all enter or leave at the **base**, and are called **arteries** if they convey blood *from* the heart, and **veins** if they convey it *to* the heart. They are described in Chap. XXIV.

5. **THE OESOPHAGUS** (Gr. *oīsophagos*, the gullet) passes down the neck close behind the trachea, between the latter and

the vertebral column, then between the lungs behind the heart, and through the diaphragm to the stomach beneath. It is that portion of the alimentary canal lying between the pharynx and stomach. It is essentially a muscular tube, about 25 cms. long, and excepting the pylorus it is the narrowest part of the canal. It begins at the lower border of the cricoid cartilage, or opposite the sixth cervical vertebra, and ends at the level of the eleventh thoracic vertebra. The oesophagus is lined with stratified epithelium throughout its length.

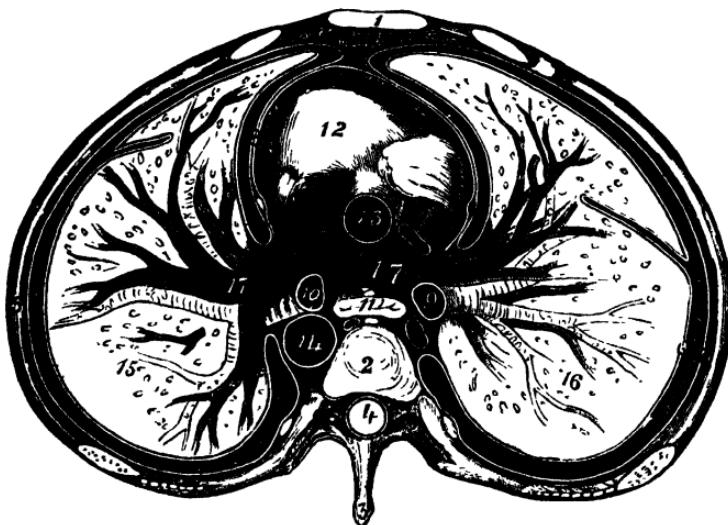


Fig. 77.—Transverse Section through the Thorax.

The section is carried above the heart, but below the division of the trachea.

1, sternum; 2, body of dorsal vertebra; 3, spinous process; 4, spinal cavity; 5, rib; 6, inner layer of pleura; 7, outer layer of pleura; 8, pericardium; 9, right bronchus; 10, left bronchus; 11, oesophagus; 12, heart; 13, aorta, ascending; 14, aorta, descending; 15, left lung; 16, right lung; 17, pulmonary arteries.

6. CŒLOMIC CAVITIES.—Both heart and lungs are invested by double fibro-serous membranes. That which surrounds the heart is called the **pericardium** (Gr. *peri*, about; and *kardia*, the heart), and that which invests each lung the **pleura** (Gr. *pleura*, a rib, or the side). In both cases one layer of the membrane is so closely attached to the organ that it can be separated only with difficulty, while the other is reflected back from this so as to form a double bag or sac. The outer layer of the pericardium, known as the **fibrous pericardium**, envelops the heart loosely, and is generally torn or cut when that

organ is removed from the thorax. The inner layer is the **serous pericardium**. It lines both the fibrous sac just mentioned and the heart itself. The outer layer of the pleura (known as the **parietal pleura**) is firmly attached to the walls of the chest.

Between the layers of pericardium and similarly the layers of the pleura is a small quantity of fluid secreted by these sacs so that these cœlomic cavities are only potential ones. The object is that of reduction of friction, for the two layers are really in contact.

Pleurisy is inflammation of the pleural membrane. It often results in the effusion into the pleural cavity of a serous fluid which may contain pus. Similarly pericarditis is inflammation of the pericardium.

The organs just mentioned completely fill the thorax during life; but when the chest of a dead animal is cut open the lungs collapse, even if they are uninjured, for they are elastic. If, however, a suitable tube be inserted in the trachea, the lungs may again be inflated by blowing into them.

SUMMARY

THE ORGANS OF THE THORAX.

Air Passages—transmit air to and from lungs.

Trachea—11 cms. long—a flexible tube.

Kept patent by 16 to 20 incomplete cartilaginous rings.

Trachealis muscle unites rings posteriorly and transversely.

Larynx—upper enlarged portion, contains vocal cords.

Bronchi—right is wider, shorter, more vertical than left.

Bronchioles—subdivisions of bronchi \pm cartilage rings.

Lungs—inflatable elastic bags for holding air.

R. lung (3 lobes), L. lung (2 lobes). O₂ in, CO₂ out.

Alveoli—terminal dilations for rapid gaseous interchange.

Heart—hollow, involuntary, muscular pump.

Occupies lower, middle, front part of chest.

Rests on diaphragm behind sternum.

Apex beat—5th left intercostal space, 3·5 inches from midline.

Large blood-vessels—aorta, pulmonary vessels, venæ cavæ.

Esophagus (food pipe)—conveys food from mouth to stomach.

Soft muscular tube, 10 inches long, in front of vertebral column.

THORACIC CŒLOMIC CAVITIES:—

Pericardial (1)—Pericardium, invests heart as a double layer.

Between layers is pericardial fluid. Inflammation is pericarditis.

Pleural (2)—Pleura, invests each lung as a double layer.

Between layers is pleural fluid. Inflammation is pleurisy.

CHAPTER XIII

THE ORGANS OF THE ABDOMEN

WE must now study the various organs of the abdomen.

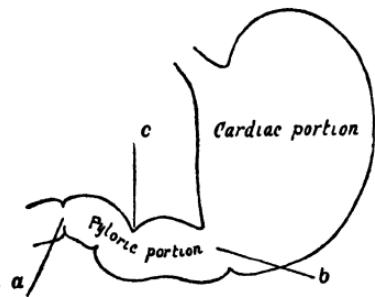
1. **THE OESOPHAGUS** in its abdominal portion is only half an inch long, and lies in a groove on the posterior surface of the left lobe of the liver. At the junction with the stomach its squamous epithelium suddenly changes to the columnar form.

2. **THE STOMACH** is a membranous and muscular bag, about ten inches in length from right to left, situated in part

against the front wall of the abdomen, just beneath the diaphragm. It lies in part under the left lobe of the liver. The stomach is of very variable shape, its larger end, called the *cardiac extremity*, being on the left, and the narrower end, called the *pyloric extremity*, on the right. That part of the stomach lying above the cardiac orifice is known as the fundus, and is often distended with gas (wind), causing eructations.

Fig. 78.—Outline of the Stomach. *a*, the pylorus; *b*, a constriction between the cardiac and pyloric portions; *c*, a well-marked notch near the pylorus.

In the erect posture, its shape is roughly that of the letter J. The upper limb of this letter represents the fundus and the cardiac part, while the rest represents the pyloric portion and the pylorus itself. The oesophagus joins the stomach at the **cardiac orifice** at the level of the tenth thoracic vertebra; and the narrow end of the stomach communicates with the intestines by a muscular opening which is called the **pylorus** (*Gr. pulouros*, a gate-keeper) at the level of the first lumbar vertebra. The right border of the stomach is short and concave, while the left border is long and convex. The former is called the **lesser curvature**, and the latter the **greater curvature**. From



the lesser curvature to the liver stretches a fold of peritoneum, the **lesser omentum**, while between the greater curvature and the transverse colon is the **greater omentum**. Above the stomach are the liver (left and quadrate lobes), the diaphragm, and the small omentum, while below it are great omentum, transverse colon, and gastro-splenic omentum. Behind are the pancreas, spleen, left kidney and suprarenal, and in front are the diaphragm, liver and anterior abdominal wall. Food enters the stomach through the cardiac orifice, and, after being thoroughly mixed with the digestive fluid of the stomach (gastric juice), passes through the pylorus into the small intestine, duodenal portion.

3. **THE INTESTINES** consist of two distinct portions, the *small intestine*, and the *large intestine*, both together occupying a large portion of the abdomen.

The **small intestine** is a convoluted tube, about twenty feet or six metres in length. It is surrounded at the sides and above by the large intestine, and has the greater omentum and abdominal wall in front of it. The small intestine commences at the pylorus and ends at the ileo-colic valve. For about 25 cms., commencing at the pylorus, it is called the **duodenum** (Lat. *duodeni*, twelve apiece, being considered to be about twelve finger-breadths long). It is characterised by the fact that it is the shortest but widest part of the small intestine. The upper two-fifths of the remainder is called the **jejunum** (Lat. *jejunus*, empty), and the lower three-fifths the **ileum** (Gr. *eilein*, to twist). There are, however, no definite lines of separation between the latter two parts, the distinction being rather one of convenience.

The small intestine, together with the cæcum, ascending colon and part of the transverse colon, is supplied by a special artery coming from the aorta—the **superior mesenteric artery**.

The **large intestine** is a wider tube, about six feet long, and varying in width, being widest at its start and gradually diminishing down to the rectum. It extends from the ileum to the anus and is divided into the following parts :—

(a) The **cæcum** (Lat. *cæcus*, blind) is a kind of pouch, situated on the right side of the abdomen, below the junction of the small intestine (the ileum) with the large intestine.

(b) The **appendix** is a narrow wormlike tube which runs into the cæcum 2 to 3 cms. below the ileo-cæcal valve. It is of very variable length, up to 20 cms., the average being about

8 cms. (four inches). It is often subject to infection and becomes inflamed (appendicitis).

(c) The colon extends upwards from this point, till it reaches the under surface of the right lobe of the liver, just to the right of the gall bladder. It then turns to the left, passing under the

stomach, to the lower end of the spleen, where it is again deflected downward and becomes the *pelvic or sigmoid colon*, which terminates in the **rectum**. Thus the colon is arranged like three sides of a square, the parts being called the **ascending, transverse, and descending colon** respectively.

The transverse, descending and pelvic colon, together with the rectum, are supplied by the *inferior mesenteric artery*.

(d) The **rectum** is about 12 cms. long and lies on the sacrum, coccyx and levatores ani muscles. The relations of its parts are important. In the male the bladder lies in front, while in the female it is the uterus. Below it in the male are the vesiculae seminales, ductus deferentes, and the posterior surface of the prostate—hence the latter can be palpated per rectum, a useful aid to diagnosis.

Fig. 79.—The Abdominal Portion of the Alimentary Canal.

c, cardiac opening of the stomach; p, pylorus; d, duodenum; j, jejunum; i, ileum; cc, cæcum; ac, ascending colon; rc, transverse colon; dc, descending colon; r, rectum; a, anus.

In the female the posterior wall of the vagina lies below it.

(e) The **anus** begins at the level of the levatores ani muscles. It is from one to one and a half inches long. Below it is the coccyx, while in front is the vagina in the female and the membranous urethra in the male. The anal canal has two



sphincters, an internal involuntary one, and an external voluntary one.

The mouth, pharynx, oesophagus, stomach and intestines together form the **alimentary canal** (Lat. *alimentum*, nourishment). Each part does its share in the digestion of the food, the separation of the nutritious from the non-nutritious portions, the absorption of digested food, and the excretion of the rest.

4. THE PANCREAS (Gr. *pan*, all; *kreas*, flesh) or **sweetbread** is an organ which secretes *insulin* by special cells known as the "islets," and the *pancreatic juice* by the ordinary

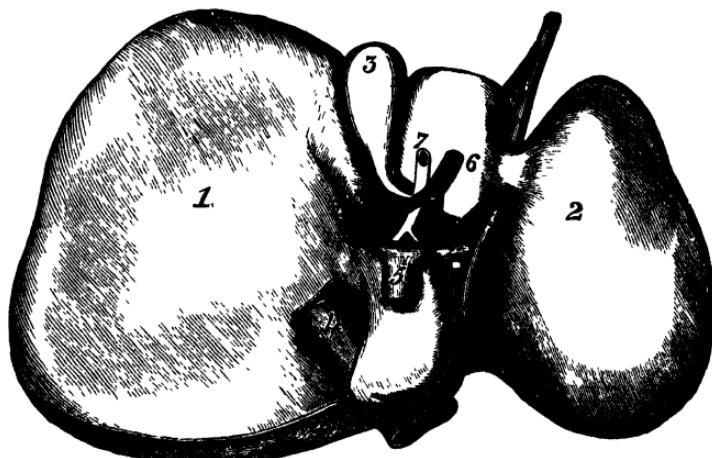


Fig. 80.—The Under Surface of the Liver.

1, right lobe; 2, left lobe; 3, gall-bladder; 4, vena cava inferior; 5, portal vein; 6, hepatic artery; 7, hepatic duct.

alveolar cells. It lies just behind the stomach and extends from the duodenum to the spleen, and consists of a head, neck, body and tail. It is about 7" long and 1½" wide, and weighs about 3 ounces. The fluid it prepares is conveyed to the duodenum by the pancreatic duct which runs through the organ from left to right. It enters the duodenum by a common orifice with the common bile duct.

5. THE LIVER AND GALL-BLADDER.—The liver is the largest gland in the body. In the adult it weighs from 50 to 60 ounces (1.5 kilograms), and forms about one-fortieth the weight of the entire body.

It is situated at the top of the abdomen, with its upper and *

convex surface fitting closely against the under and concave surface of the diaphragm.

The liver (Gr. *hepar*) consists of two lobes—the right and the left. Of these the right is about six times larger than the left. The former also extends well over the right upper portion of the abdomen, while the latter is not large enough to reach the left

side of the body, although it lies over a considerable portion of the stomach. Each lobe is subdivided into lobules of approximately polyhedral shape, and about 1 mm. in diameter. Each lobule is composed of a fine network of connective tissue which supports the liver cells.

The upper, convex surface of the liver is very smooth and regular; but the under surface is most irregular, and is broken by the entrance and exit of the various vessels which belong to the organ.

The liver is extremely well supplied with blood-vessels, and in it the blood is deprived of a large quantity of the impurities which it has gathered from the various parts of the body.

It is almost entirely surrounded by folds of the **peritoneum**, which

Fig. 81.—The Portal Vein and its Tributaries.

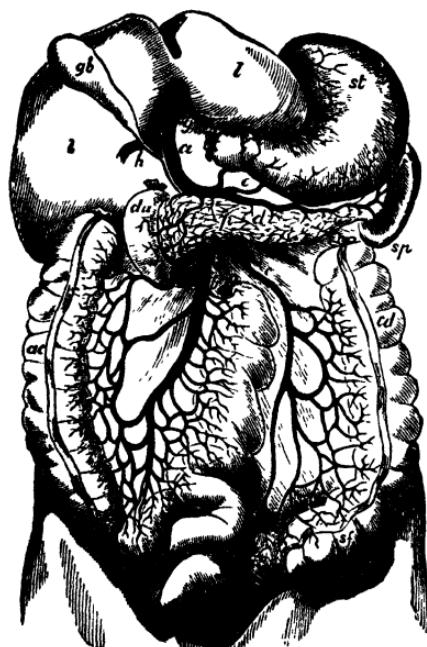
l, liver, under surface; *gb*, gall-bladder; *st*, stomach; *sp*, spleen; *p*, pancreas; *du*, duodenum; *ac*, ascending colon; *cd*, descending colon; *a, b, c, d, e*, the portal vein and its branches. Portions of the duodenum and colon have been removed.

serve to retain it in position. One fold, the falciform ligament, connects the upper surface of the liver to the under surface of the diaphragm and the anterior abdominal wall.

The vessels of the liver are—

The portal vein, the hepatic artery, veins and ducts.

The first three of these are blood-vessels, and the last conveys away from the liver a fluid called the **bile**, which is prepared from



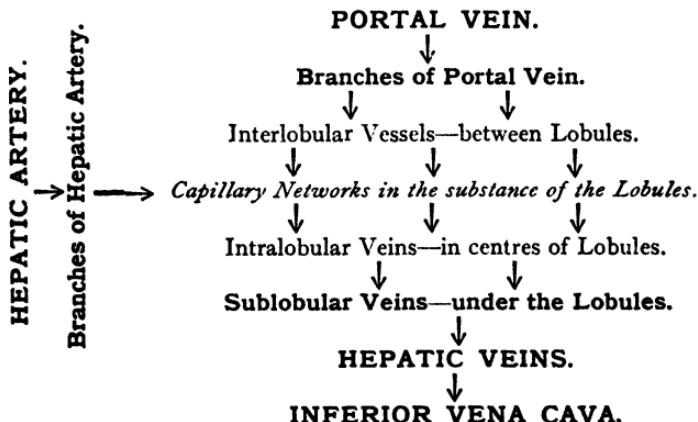
the blood. The first two convey their contents to the organ, and the last two from it.

(a) The **portal vein** (Lat. *vena portæ*, or vein of the gate—the gate being the depression between the lobules of the liver) conveys to the liver a large volume of blood which it collects from the veins of the *stomach*, *intestines*, *pancreas* and *spleen*. This blood has already circulated through the capillary systems of these organs, and is therefore of a dark purple colour, and at the same time is very rich in nutritious matter. It is about three inches in length, and is formed by the junction of the splenic and the superior mesenteric veins, just behind the neck of the pancreas and in front of the inferior vena cava. In the liver it breaks up into capillaries as an artery would.

(b) The **hepatic artery** brings to the liver a supply of oxygenated blood direct from the descending branch of the aorta. The office of this blood is to supply oxygen for the structure of the liver itself, whereas the portal blood has to be specially dealt with by the liver cells.

(c) The **hepatic veins** collect up the blood of both these vessels, after it has circulated through the capillaries of the liver, and convey it directly into the inferior vena cava.

COURSE OF THE BLOOD THROUGH THE LIVER

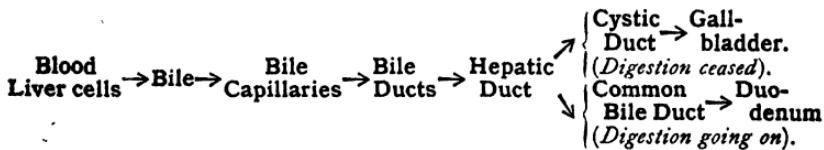


(d) The **hepatic duct** conveys the bile into the gall-bladder or into the duodenum—to the former, *via* the cystic duct if digestion is not going on, and to the latter, *via* the common bile duct if the digestive organs are active.

The spaces between the blood-vessels of the liver are filled with minute cells, about 20μ in diameter, called **hepatic cells** or **liver cells**. The blood capillaries run between these, and all changes which occur in the blood as it circulates through the liver are brought about by the action of the cells, which are separated from the blood only by the exceedingly thin walls of the capillaries. But according to many these capillaries have deficient endothelium, *i.e.* the liver cells are in actual contact with the blood. In technical language these irregular spaces without proper walls are known as **sinusoids**.

The materials which are separated from the blood in the blood capillaries appear to pass through the liver cells to another set of microscopic vessels called the **bile capillaries**. These vessels arise as spaces between contiguous liver cells, *i.e.* they also have no special walls of their own. These unite to form small **biliary ducts**, which by their further union eventually form the two hepatic ducts. One conveys the bile from the left lobe, and the other from the right, while both unite to form **the hepatic duct**. This duct is accompanied by the portal vein and hepatic artery. The gall-bladder is connected with this tube by a duct of its own, called the **cystic duct** (Gr. *kustis*, a bladder), and these two unite into the **common duct**, which leads direct to the duodenum.

COURSE OF THE BILE



The **gall-bladder** is a pear-shaped musculo-membranous bag, situated in a cavity (fossa) on the under surface of the liver. It is supported by the peritoneum, which passes below it ; and its broader end projects beyond the front margin of the liver. The cystic duct is connected with the narrow end.

6. **THE SPLEEN** (or milt) is a dark purple organ, weighing about 200 grams (6 oz.) and lying between the diaphragm and the fundus of the stomach. It will be considered in detail in the chapter on the circulation.

7. **THE URINARY ORGANS**—kidneys, ureters, bladder and urethra—will be described in Chap. XXIX.

SUMMARY**THE ORGANS OF THE ABDOMEN.**

1. **Œsophagus**—abdominal portion, $\frac{1}{2}$ " opposite 10th thoracic vertebra.
2. **Stomach**—a musculo-membranous bag of variable capacity.

Openings .	{ Cardiac—left side, opposite 10th thoracic vertebra. Pyloric—right side, opposite 1st lumbar vertebra.
Relations .	{ Above—liver, diaphragm, small omentum. Below—great omentum, transverse colon. Behind—pancreas, spleen, L. kidney and suprarenal. Front—diaphragm, liver, abdominal wall.
Nerves .	Vagi and sympathetic.
3. **Small Intestine**—6 metres long. Divided into three portions:—
Duodenum—25 cms. Common bile duct, Brunner's glands.
Jejunum—230 cms. Large villi.
Ileum—350 cms. Smaller villi. Peyer's patches.
4. **Large Intestine**—150 cms., or 6 feet long.
Cæcum—6 cms. Lies in right iliac fossa.
Appendix—2 to 20 cms., variable length and orientation.
Colon—ascending (15 cms.), transverse (50 cms.), descending (25 cms.), iliac (15 cms.), and pelvic (40 cms.).
Ileo cæcal valve—at junction of ileum, cæcum, colon.
Rectum—12 cms. In front is the bladder (δ), uterus (φ).
Anus—3 cms, has two sphincters. Internal is involuntary, external is voluntary.
5. **The Liver**—weight 1·5 kilos (50–60 ozs.).
Lobes—Right, six times size of left.

Relations .	{ Above—diaphragm, abdominal wall. Below—cardiac end stomach, R. kidney. Duodenum, colon (hepatic flexure). Behind—10–11th thoracic vertebræ, œsophagus, great vessels.
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6. **The Pancreas**—weight 3 ounces.
Lies between duodenum, spleen, stomach, L. kidney.

CHAPTER XIV

BIOCHEMISTRY

BIOCHEMISTRY (Gr. *bios*, life) is the study and interpretation of all the chemical changes in living matter. From the point of view of physiology this includes the composition of the body, the food eaten (animal and vegetable), the changes the food undergoes in the body, and the nature of the processes which bring about these changes.

Of the 87 or so elements known to the chemist only a few, perhaps about 16, are found habitually in the human body. The most abundant are C, H, O, N, S, P, Na, Ca, Cl, Mg, and small traces of others such as Fe, I, F and Cu. Only three exist in the free as well as the combined state, viz. N and O dissolved in the plasma, and H produced in the gut by bacterial decomposition. Oxygen, however, is the only element actually assimilated in the free state.

CLASSIFICATION OF ANIMAL AND PLANT SUBSTANCES.—This is a difficult matter owing to the very large and varied number of such compounds, and their complicated and often quite unknown composition. Biochemists have therefore adopted a broad scheme of classification, which has a good practical basis if not a scientific one. We consider here only such compounds as are of interest to the human physiologist, since some are used as foods, while others tell us of the changes that go on in the body.

1. **CARBOHYDRATES** contain C, H, and O in the form $C_x(H_2O)_y$. They constitute a large part of animal and plant tissues. Chemically they are complexes of substances called monosaccharides, of which glucose is a well-known example. Carbohydrates form the structure of plants (as cellulose) and serve as reserve food material—starch in plants, and glycogen in animals.

(a) **Starches** are complicated compounds of the monosaccharides. In consequence they either do not dissolve in water (*e.g.* cellulose) or if so then they do not form true solutions, that is, they are colloidal (*e.g.* glycogen). Some act as food

reserve material, as starch in cereals or potato, and glycogen is stored in the liver and muscles of animals.

(b) **Sugars.**—The important ones in physiology are the disaccharides, such as cane sugar (sucrose), maltose (in germinating cereals), lactose in milk, and the monosaccharides into which these hexoses are converted by the digestive juices, viz. glucose, fructose and galactose. To some extent they are found naturally—e.g. glucose in fruit.

2. **FATS OR LIPIDES** contain C, H and O, with sometimes P and N. From the chemical point of view, fats are glycerol esters of certain fatty acids (stearic, palmitic and oleic). They are insoluble in water. Chemically they may be split up (hydrolysed) into glycerol and fatty acid by aid of certain glandular secretions known as enzymes.

Fats are met with in the protoplasm of all cells. They are found in abundance in the human body in adipose tissue, between the muscle layers, and in large masses around some of the viscera, such as the heart and kidneys. It is also found in bone marrow, especially in adult life, where it may form as much as 96 per cent. of the yellow marrow of the medullary cavities of the long bones. Fats also exist in milk as an emulsion of very fine globules, and are also found as reserve food material in many plants, where they are known as oils. There is no chemical difference between fats and oils. The chief vegetable oils are olive oil, cotton-seed oil, and linseed oil.

There are also certain other bodies allied to the fats called **lecithins** and **sterols**. The former are abundantly found in brain tissue, liver and egg yolk, while the latter in the form of cholesterol is found in the bile, bone marrow and nervous tissue. Gallstones consist almost entirely of cholesterol.

3. **THE PROTEINS** are complicated colloidal organic substances containing C, H, O, N, S, and sometimes P. They may be regarded as complexes of certain simpler bodies known as amino acids, in the same way that carbohydrates are complexes of monosaccharides. Proteins are abundant in all animal and plant cells and tissues. Thus egg-white and lean meat consist almost entirely of it, while there is quite a large amount in some seeds and fruits and in milk. In general, more than a half of protein substances consists of oxygen, a little less is nitrogen, still less hydrogen, and the rest is sulphur, and sometimes phosphorus.

4. **VITAMINS** are substances present in the food in minute quantities. They are absolutely essential to the normal

healthy life and growth. Animals fed on an experimental diet of pure carbohydrate, fat, protein, water and salts, are found not to thrive. This is rather an unexpected result, for all care is taken to secure the right sort and proportion of each constituent. In man various diseases have been noted as the result of the omission of certain constituents of his normal diet. Moreover, if these missing constituents are added recovery is complete. There is something in "natural" food which is absent in "synthetic" food. These substances are known as "vitamins," though the name is now known to be incorrect, for they are not amines. Further investigation has shown that extracts of these necessary foods are as good as the foods themselves, so far as the restoration to normal health is concerned. The amount of vitamin obtained from food is incredibly small, showing that in no case can they act as givers of energy. Much of the experimental work has been done on animals, and the condition produced in them as a result of the withholding of vitamins is called **avitaminosis**. The corresponding condition in man has received another name, **deficiency disease**, for there may be other complicating factors in his case.

Vitamin A (growth-promoting) is present in animal fats, but ultimately it all comes from green plants. It is therefore found in milk, butter (not margarine), cream, liver and beef fat. The best source of all is cod-liver oil. If this vitamin is omitted from the diet of animals there is a lack of growth and an increased liability to infection, especially of the eyes (xerophthalmia), respiratory passages and gut. Vitamin A is formed in the liver from the carotene of plants, a well-known vegetable pigment. Fish get their vitamin A (and D) content from the mass of plankton upon which they feed in the sea, and the latter again derive their supply from the green diatoms—the ultimate source.

Vitamin B₁ (anti-beriberi) is found in fresh vegetables, seed husks, yeast (marmite), meat and eggs. Its omission from the diet, as by feeding birds on water and polished rice, produces an experimental condition called **polyneuritis**. The corresponding clinical condition in man is **beriberi**.

Vitamin B₂ (pellagra preventing) is always found associated with B₁. The corresponding avitaminosis is a form of dermatitis (pigmentation and erythema). In man the deficiency disease is known as **pellagra**, curable by the administration of yeast.

Vitamin C (anti-scorbutic) is found in fresh fruit, especially oranges and lemons, and in fresh vegetables (spinach and cabbage). Its absence in man leads to **scurvy**, characterised by haemorrhages in gut, skin and bones, with tenderness of the joints. Scurvy can be produced in infants fed entirely on artificial and sterilised food.

Vitamin D (anti-rachitic) is found in association with vitamin A in yolk, butter and fish-liver oils. It is present in animal but not in vegetable fats. Vitamin D is essential for the metabolism of calcium and phosphorus, and is therefore specially concerned with the proper calcification of bone and teeth. If absent from the diet it leads to **rickets** and **dental caries** in the child, and **osteomalacia** in adult women. Irradiation by (i.e. exposure to) ultra-violet rays leads to its production in the body from the ergosterol content of the tissues.

Vitamin E (anti-sterility—in rats) is present in vegetable oils, green leaves and seeds. Rats kept deficient in this vitamin are sterile, both males and females. It is doubtful if this applies to human beings, though it is being tried in certain cases of sterility for which no reason can be determined.

Yet other vitamins have been described, and will doubtless be discovered. Their mode of action is quite unknown. Like enzymes and the autacoids, they act in minute quantities. It is therefore unlikely they can have any energy value. They may be of the nature of catalysts.

5. INORGANIC SALTS.—A certain amount of mineral matter enters into the composition of all living cells, the proportion and nature varying of course with the particular animal or plant tissue. The actual amount and precise nature of these salts is determined by burning (cremation) until only ash is left—the organic matter having been burned off as CO_2 and H_2O . The ash can then be subjected to chemical analysis. More modern methods of dealing with the cells enable analyses to have much greater significance and with more approximation to the actual conditions in life than the above. Removal of the organic matter by such means as dialysis (separation through membranes) or chemical precipitation are now employed as well as incineration.

The chief inorganic constituents are:—Carbonates and phosphates of Ca, K, Mg and Na; chlorides and sulphates of Na and K; nitrogen derivatives such as urea, ammonium salts; also salts of iron.

6. AUTACOIDS (Gr. *autos*, self; *akos*, a remedy) are

autogenous or self-made substances manufactured in the body, each by its own special organ, to be used in some other organ for the chemical control of the body. They are often known as hormones (Gk. *hormao*, I arouse to action), though the name is not always appropriate (see Chap. XXXVIII).

7. **PIGMENTS** are coloured substances, very common in the animal and plant world. They are present in bile (as biliverdin, bilirubin), in blood (as haemoglobin), in green leaves (as chlorophyll), in the retina (as visual purple), in the deepest layer of the skin, especially in dark-skinned races (as melanin).

8. **NITROGENOUS BASES**, such as histamine, acetyl choline, creatin, are also found. These will be described later.

9. **PURINES** are a special group of N containing compounds produced by the decomposition of nucleo-proteins. Uric acid, and caffeine are familiar examples.

10. **WATER** makes 70 to 80 per cent. of most tissues, and more than 90 per cent. of the secretions.

SUMMARY

CLASSIFICATION OF ANIMAL AND PLANT SUBSTANCES.

1. **Carbohydrates**— $C_x(H_2O)_y$. Monosaccharide complexes.

They form the structure and food reserve of plants.

2. **Fats (lipides)**—C, H, O, sometimes P and N. Glycerol esters.

Animal fats, vegetable oils, lecithins, sterols.

3. **Proteins**—C, H, O, N, sometimes P and S. Amino acid complexes. Essential for growth, repair.

4. **Vitamins**—essential micro-constituents of foods—for normal growth and development.

A. Growth-promoting. In animal and fish oils.

B₁. Anti-beriberi } In yeast and seed husks.

B₂. Anti-pellagra } In fresh milk, fruit and vegetables.

C. Anti-scorbutic. In animal fats and fish oils.

D. Anti-rachitic. In vegetable oil and seeds.

E. Anti-sterility (rats). In vegetable oil and seeds.

5. **Inorganic salts**—Ca and P for bones, Fe for haemoglobin, iodine for the thyroid gland, Ca, K, Na for muscle.

6. **Autacoids (hormones)**—autogenous specific substances made in one organ, and used by another for the chemical control and co-ordination of the body.

7. **Pigments**—haemoglobin, chlorophyll, bile.

For various purposes—photochemical, respiratory, etc.

8. **Nitrogenous bases**—histamine, acetyl choline, adrenaline, urea.

9. **Purines**—related to uric acid and derived from nucleo-proteins.

10. **Water**—70 to 80 per cent. of tissues, 90 per cent. of secretions.

CHAPTER XV

FOOD

NECESSITY FOR FOOD.—All living matter is of the nature of a machine in that it uses up energy, converting some into work and most into heat. Moreover, there is the ordinary wear and tear of the tissues to make good, the material for growth to be provided for, if the animal is young, and there is always a certain amount of waste. All this can be made good by the provision of food ; in fact, the greater part of the lives of most animals is taken up with a continual hunt for food.

Food is anything taken into the body for the purpose of growth, repair, the production of heat and work, and the supply of body regulators (hormones, vitamins and enzymes). This food has, however, to be first rendered suitable for absorption, *i.e.* it has to be digested. After absorption it has to be oxidised for the immediate production of heat and work, or else stored or used for repair and growth, as the case may be.

The chemical nature of our food has been considered in the last chapter. We have now to investigate the relation of this food to the material composing our bodies, for though similar, yet it is not identical with our food whether animal or vegetable. The albumin of egg white is not the same as our own plasma albumin. When we eat the former it is not absorbed as such, neither does it act as a substitute for our own albumin. The same is probably true of most of the constituents of the food, except the inorganic portion. If we feed on **beef** fat, the fat in our bodies is still our own particular brand of fat, with those characteristics known to the organic chemist, and equally to the cannibal (though in a different way), as **human** fat.

FOOD REQUIREMENTS.—It is necessary to study now in more detail the nature of the various foods and foodstuffs eaten. By this we mean, for instance, that when speaking of "bread" scientifically we are merely taking a particular example of the carbohydrate foodstuff starch. It is from this point of view that physiologists consider the food we eat. We therefore study the matter under the following headings :—

1. PROTEIN REQUIREMENT.—There is a continual loss of nitrogen (as urea, uric acid) from the body, due to wear and tear. This has to be made good, and, moreover, in the growing child new tissue has to be formed. For these reasons we have to keep up a nitrogenous equilibrium, which of course is done by eating foods containing protein. Each type of protein, such as fish, cheese or milk, contains different amino acid constituents and in different proportions. The body not being able to convert one into the other, the diet must be so arranged that it covers all requirements in this respect which means that we should indulge in mixed protein foods. Moreover, proteins are the only foods containing N and S in forms which can be assimilated by the cells of the body. In general, man requires about 100 grams of mixed protein daily in his diet.

2. FAT REQUIREMENT.—Fats are necessary, since their heat value is great, more than twice that of either proteins or carbohydrates. In addition they are stored in the sub-cutaneous tissue of the body, to be used in time of want. It is found that about 100 grams (3·5 ounces) of fat represent the average daily need. Animal fats are also important sources of vitamins A and D.

3. CARBOHYDRATE REQUIREMENT.—All carbohydrate food is ultimately converted into glucose, and it is this which provides us with a ready source of energy for muscular contraction. Also it is now known that some amount of carbohydrate is necessary for the proper combustion of fat. In general, the average diet should contain about 500 grams of carbohydrate daily.

4. INORGANIC SALT REQUIREMENTS.—These are just as essential for life as the above three energy producers. Though an animal may be fed with the correct amounts and proportions of fats, carbohydrates and protein, yet if salts are withheld it will languish, refuse its food, and eventually die. Quite a varied selection of inorganic salts is needed, the more so since they are being continually lost *via* the urine. They help in the general building up of body tissue and energy production (though they themselves have no energy value), in the maintenance of osmotic pressure, and the reaction of the body fluids. Thus calcium is necessary for the building up of bone and muscular contraction, and also for the clotting of blood, iodine is required for the secretion of the thyroid gland, phosphates also for the bones, iron for the haemoglobin of the

red blood cells, while muscle needs Ca, K and Na. The amount of salts found in any ordinary mixed diet is ample for all requirements, and really needs no further consideration. The usual consumption of common salt NaCl (10 grams per day) is quite beyond all real need.

5. WATER REQUIREMENT.—To appreciate the importance of water it is only necessary to realise that 70 per cent. of the body weight consists of water, that five or more litres are given off daily:—sweat (700 c.c.), faeces (100 c.c.), breath (400 c.c.), urine (1,500 c.c.) and other secretions. Of this, half a litre may be produced by oxidation, and roughly about a half of the solid we eat is water, leaving about 1,500 c.c. to be actually imbibed as fluid each day. It is clear that the amount, however, depends very largely upon the nature of the diet.

6. VITAMIN REQUIREMENT.—This is probably best secured by ignoring that contained in the food, and seeing to it that fresh fruit (for C and E), some preparation of yeast (for B₁ and B₂), cod-liver oil (for A and D), are taken. The two latter need only be taken occasionally. It is said “An apple a day keeps the doctor away.” We do not at present know of any ill effects due to **excess** of vitamins in our food.

ANIMAL PROTEIN FOODSTUFFS.—Some of the more familiar of these are :—

(a) **Albumin**, found in white of egg and plasma. It is a clear white transparent liquid which coagulates when heated to an opaque solid. This change is irreversible, for cooling does not reverse the process.

(b) **Globulin** is somewhat similar to albumin, and is found associated with it.

(c) **Casein** (Lat. *caseus*, cheese) is produced from the caseinogen of milk. The addition of rennet causes the casein to separate out as a clot, and from this cheese is made.

(d) **Fibrin** (Lat. *fibra*, a fibre) is the mass which makes up the framework of a blood clot. It is formed from a substance in the blood, fibrinogen.

(e) **Myosin** (Gr. *mus*, a muscle) is an important constituent of meat juice.

(f) **Gelatin** is obtained from bone and cartilage by boiling. It swells up in cold water, but does not dissolve, forming a colloidal solution. It is soluble in hot water, forming a jelly, or it is said to “gel” on cooling.

VEGETABLE PROTEIN FOODSTUFFS.—Some of the more common ones are :—

(a) **Gluten** is found in all cereals, from which it may be obtained by washing. Tie a little wheat flour in a muslin bag and well knead it in water. A substance passes through the muslin which gives the water a milky appearance. This is starch. After removing as much of the starch as possible the contents of the bag will be found to consist of a sticky substance which can be pulled into threads. This is the gluten. It is really a mixture of two proteins, **gliadin** and **glutelin**, to the former of which the sticky character is due. Hence flour poor in gliadin, as for instance rice flour, is unsuitable for bread-making.

(b) **Plant globulins.** Good examples are the **legumin** of peas and beans, **zein** from maize, **edestin** from cotton seeds.

(c) **Plant albumins**, such as the **leucosins** of cereals.

SOURCES OF LOSS TO THE BODY.—It is of importance to consider the various ways in which our bodies lose energy and material. These may be summed up as follows :—

1. The **lungs** daily cause the loss of about 400 c.c. water vapour (and therefore also heat) and CO₂.

2. The **skin**, through the process of perspiration (*via* the sweat glands), makes us lose water. Heat is also lost through the latent heat of evaporation of that moisture. Sweat is 99 per cent. water. The amount lost this way, however, is very variable. Perhaps 700 c.c. per day represents a fair average.

3. The **kidneys** are a source of considerable loss of water (1,500 c.c. daily), salts, urea, uric acid, and other substances.

4. The **alimentary canal**, though enabling us to get rid of undigested and indigestible food (skins, cellulose) which are neither a source of loss or gain, since they have never been absorbed, yet it does bring about the loss of a great deal of material from the body—digestive juices, dead bacteria, cellular debris and water. The faeces of a starving man still contain a great deal of intestinal juices, bacteria and mucus.

STANDARD FORMS OF FOOD.—We begin by considering whether any food is in itself all sufficient, or is a "perfect food," in the technical sense. Such foods would have to contain the protein, carbohydrate, fatty, and inorganic constituents in the correct proportion for growth, repair and maintenance. Taken in this sense there are few other perfect foods than milk and eggs. Some species of caterpillars live only on *one* particular sort of leaf. If given any other variety they languish and die.

1. **Milk** is only perfect for those for whom it is by nature intended. By this not only is it meant that milk is requisite for babies under nine months of age, but it must be human milk, and, indeed, that from the babe's own mother. Of course, in practice this cannot always be carried out, and at best cow's milk is but a moderate substitute, and that at a greatly increased cost and trouble in its preparation. Milk in this sense is unsuitable for adults, in that to get sufficient of the necessary food materials too bulky drinks (and too often) would be required. Moreover, the proportion of the several constituents would be incorrect, for it has too much protein and fat, and too

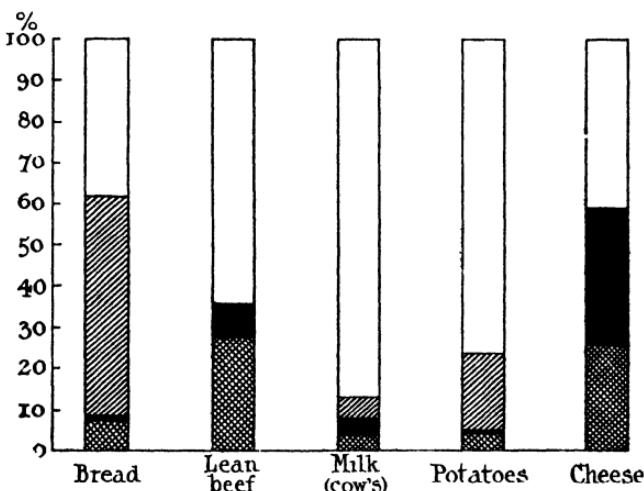


Fig. 82.—Composition of Staple Foods (diagrammatic).

The unshaded portion represents water and salts; the blackened portion fat; the striped portion carbohydrate, and the doubly striped portion protein.

little iron. It is important to know the composition of milk, and particularly to contrast it with that of the cow, or other animal (*e.g.* ass or goat) used as a substitute.

The proteins of milk are lactalbumin and caseinogen. This latter is clotted or coagulated by rennin to form what is called junket, while prepared in another way and entangled with fat it forms cheese. The fats of milk form butter, which as a fat is far more digestible than vegetable fat, and should be used in preference. The salts in milk are calcium phosphate and chlorides of sodium and potassium. From the table it is clear that cow's milk contains too much protein and not enough

lactose. Hence to feed a baby on cow's milk, the latter should be diluted to reduce the high protein content. Since this also reduces the fat and sugar, suitable amounts of these must be added to compensate. Cane sugar will do instead of lactose, except in the case of premature babies. The addition of a few drops of cod-liver oil will provide the necessary vitamins A and D, and a little fresh orange juice will add C.

2. **Eggs** are similarly all sufficient for young birds, fish, amphibians and reptiles, referring, of course, only to those which are oviparous. A glance at the table below will show that there is a great difference between the white and the yolk, the latter containing a large amount of fat, and the former none. Eggs are also useful in providing vitamins A and D.

3. **Meat** is our chief source of protein—in the form of **myosin**. It is readily assimilable and of good relish, but it is costly. Note that even lean meat contains a high percentage of water, and that even in the leanest of meat there is still a fair amount of fat, for it lies in the loose areolar tissue between the muscle layers.

4. **Bread.**—The cereal flours from which the different varieties of bread are derived contain a large amount (68 per cent.) of carbohydrate, present in the form of starch. In the form of bread there is 35 per cent. carbohydrate and 9 per cent. protein, with a very small amount of salts, fat and cellulose. Carbohydrates are the cheapest form of food.

5. **Various foods.**—It is of interest to know that butter contains something like 85 per cent. of fat, cheese 30 per cent. fat and 25 per cent. proteins, oatmeal 8 per cent. fat and potatoes none. Solid chocolate is 50 per cent. fat, 30 per cent. sugar and 10 per cent. protein.

THE APPROXIMATE PERCENTAGE COMPOSITION OF SOME COMMON FOODS

	Human milk	Cow's milk	Egg white	Egg yolk	Bread	Meat	Fowl	Fish
Proteins . . .	1·5	3·5	12·0	15	9	20	23	18·0
Carbohydrates . . .	6·0	4·0	0·5	1	53	1	1	1·0
Fats . . .	3·5	4·5	—	33	1	8	4	0·7
Salts . . .	0·2	0·6	0·6	1	1	1	1	0·8
Water . . .	88·8	87·4	87·0	50	36	70	71	80·0

ADJUNCTS TO FOOD.—It is usual to take other constituents into our food in order to make it more palatable rather than to add nutriment.

1. **Condiments** are seasoning or flavouring agents, such as pepper, mustard, ginger, etc.

2. **Beverages**, such as tea, coffee, cocoa, lemonade, and alcohol in its many forms. Cocoa is rich in fat (30 per cent.) and protein (20 per cent.), and so is really a food. Tea and coffee are fragrant and stimulating, the latter effect being due to their caffeine content. Alcohol is not a mental stimulant, rather does it tend to remove one's natural inhibitory powers.

3. **Fruits** contain something like 80 per cent. of water. They are of value for their taste and vitamin C content, but only if fresh. Tinned and stewed fruit are of no use in this respect. However, they act as gentle laxatives.

4. **Vegetables** are also of little value as food—90 per cent. water, and the rest mostly cellulose, which is completely indigestible to human beings. However, it serves a useful purpose as ballast or roughage, and there is the vitamin C content that is of value.

THE ESSENTIALS OF A GOOD DIET.—From the foregoing it will be understood that there are certain essential requirements when considering what is an adequate or satisfactory diet. One has to bear in mind not only the purely scientific or physiological aspect of the diet, but also its palatability and cost.

The following is therefore a list of such essentials :—

1. The diet must have a proper diet heat value adapted to the needs of the particular individual concerned. This must be particularly borne in mind when assessing the diet of a diabetic patient, growing children, and those undergoing severe manual labour.

2. It must have the proper proportion of salts, fats, carbohydrates, proteins, inorganic salts and water.

3. There must be an ample vitamin content.

4. The food must be appetising, well cooked and digestible.

Unfortunately, in spite of the valuable results of modern scientific research on food values, millions allow religion or racial custom to dictate their dietaries, and food faddists abound.

SUMMARY

FOOD REQUIREMENTS.

- 1. **Proteins**—essential for repair and growth, not stored in body.
 - Sole source of N, S, and P in a readily assimilable form.
 - Albumin globulin—egg white, plasma, muscle.
 - Casein—milk-cheese.
 - Gelatin—boiled bone.
 - Legumin—peas, beans.
 - Fibrin—blood clot.
 - Myosin—muscle (meat).
 - Gluten—cereals (bread).
 - 2. **Carbohydrates**—sources of muscular energy, heat and storage.
 - Starches—cereal starch, glycogen (cellulose).
 - Sugars—lactose (milk), maltose (barley), glucose (fruit).
 - Sucrose (cane, maple, beet).
 - 3. **Fats (lipides)**—for heat, muscular energy and storage.
 - Animal fats—marrow, milk, beef and mutton fats, fish oils.
 - Vegetable oils—olive oil, cotton-seed oil, cocoa butter.
 - 4. **Vitamins**—for normal growth and development.
 - Cod-liver oil supplies A and D; fresh fruit provides C, and some preparation of yeast provides B₁ and B₂.
 - 5. **Inorganic salts**—to maintain osmotic pressure and reaction of body fluids. Also to replace continual loss *via* the urine.
 - 6. **Adjuncts**—condiments, beverages, fruits, vegetables.
- SOURCES OF LOSS TO THE BODY**—all subject to variations.
- 1. **Lungs**—water vapour (and therefore heat) and CO₂.
 - 2. **Kidneys**—water (1,500 c.c. daily), salts, urea, uric acid.
 - 3. **Skin**—by perspiration (99 per cent. water).
 - 4. **Gut**—water, digestive juices, mucus, cellular debris, dead bacteria.

CHAPTER XVI

DIGESTION—ENZYME ACTION

BEFORE the great mass of our food can be of any service to the cells of the body it is necessary that it should be reduced to a condition in which they can utilise it. This means that not only must it be soluble, but in such a chemical state as is acceptable, or such that the mechanism of the cell can deal with. In a few cases this may be a relatively simple matter. For instance, the inorganic salts and glucose need no preparation at all, but this is far from being the case with the great majority of the food we eat. The bread, butter and meat need to undergo considerable modification before their reduced products can be absorbed into the cell protoplasm.

DIGESTION is that set of processes which swallowed food undergoes whereby it is reduced to a condition in which it can be absorbed by the living cells of the body.

To bring all this about needs a great deal of apparatus, using both physical and chemical means. Moreover, the apparatus will differ according to the character of the food partaken, *i.e.* whether carbohydrate, protein or fat, and means must also be taken to dispose of any refuse matter. This requires a very complicated mechanism, not only in regard to the details of its component parts, but also to some very efficient scheme of co-ordination and control between different departments, so to speak. It therefore follows that we have to study the subject of digestion from several aspects—mechanical, chemical and nervous.

1. **MECHANICAL PROCESSES IN DIGESTION.**—These are mainly concerned with the subdivision of the food and its internal transport.

(a) **Mastication** is the process whereby the food is mechanically divided and subdivided in the mouth. We do a little with knife and fork, but far better is it done by the jaws, teeth and associated muscles, using the principle of the lever.

(b) **Deglutition** or swallowing is the task of transporting the food along from the mouth to the stomach—a very complicated act.

(c) **Peristalsis** is the process of passing on the food in the stomach and intestines.

(d) **Segmentation** is yet another mechanical process which ensures a very thorough mixing of the food with the alimentary secretions so that the various chemical processes may be the more effectively carried out. It only occurs in the small intestine.

2. THE CHEMICAL PROCESSES IN DIGESTION.

—These are all concerned with the reduction of the large chemical molecules that make up our food substances (*e.g.* albumin) into smaller ones, which are soluble and capable of absorption. This is done by a process known to the chemist as "hydrolysis," and it is immensely facilitated by the aid of what the physiologists call "enzymes," or better, "biological catalysts." It is thereby ensured that digestion is not too slow a process and can be carried on at body temperature, which would not be the case were it not for the wise use made of these enzymes.

3. CO-ORDINATED CONTROL OF DIGESTION

not only in reference to its own parts, but also to the rest of the body. The various digestive processes must go on in orderly sequence, and this is effected by two different means :—

(a) **Nervous Control.**—This is itself of a double nature, for one set of nerves (the parasympathetic) is activating (or inhibitory) and the other (sympathetic) is inhibitory (or stimulating). These only modify the normal activity of the system, *i.e.* they increase or decrease the glandular secretions or muscular effects.

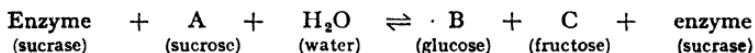
(b) **Chemical (Hormonic) Control.**—In this case a chemical substance produced in one organ is carried by the blood-stream to another part or organ which it influences. These chemicals are called hormones because they stimulate some organ. Thus the **secretin** from the upper portion of the gut is carried to the pancreas, which it stimulates to produce a strongly alkaline juice.

ENZYME ACTION.—We have already explained that enzymes or biological catalysts are substances which accelerate a chemical reaction. They are produced by living cells, both in the animal and plant world. They are soluble in water, of large molecular size, and therefore colloidal in nature. The substance upon which the enzyme acts is known as the substrate. The name of the corresponding enzyme is that of its substrate with the termination -ase added. Thus amylase is the enzyme which acts on amylose, or starch. There are certain properties which are common to all enzymes.

PROPERTIES OF ENZYMES.—Some of the more important of these are :—

1. They are specific—each acts on its own particular substrate.
2. Enzymes are killed or “inactivated” by heat (boiling).
3. Each works best at some particular temperature, and some particular degree of acidity or alkalinity (known now as “reaction”). Hence we say that each has its own optimum range of temperature and reaction.
4. The products of enzyme activity tend to recombine and yield the original substance. Hence, ultimately an equilibrium is attained whereby as much is decomposing as is reuniting at any one moment, that is, enzyme action is reversible. If one of the products is removed, as so often happens, then the reaction proceeds until equilibrium is once more reached. In this way the reaction may with equal facility proceed in either direction.
5. Associated with enzymes are co-enzymes, activators and anti-enzymes.

MODES OF ACTION.—Enzymes act by adsorption. The commonest method is that known as hydrolysis. This means that the substrate unites with water and then divides into two portions. As a chemical equation it may be written :—



Note that in the end the enzyme is still unused, so that its powers are theoretically unlimited. “A little leaven, leaveneth the whole.” Other enzymes act by oxidation or reduction, and rennin acts by coagulation.

THE CLASSIFICATION OF ENZYMES is based on the nature of the substrate. Many enzymes are known in the biological world, those of physiological interest being :—

1. **Polysaccharidases** (amylases) convert starches into maltose. Examples are the ptyalin of the saliva, and the amylase of the pancreas.

2. **Saccharidases** which convert compound sugars into the simpler ones, the monosaccharides. Thus we have maltase converting maltose into glucose ; sucrase (invertase) converting sucrose to fructose and glucose ; and lactase changes lactose into galactose and glucose. All these enzymes are found in the intestinal juice.

3. **Esterases** (lipase) hydrolyse the glycerol esters to fatty acid and glycerol. Thus we have the pancreatic lipase known as trypsin, gastric lipase and intestinal lipase.

4. Proteinases which convert proteins to peptones, or bring the reduction to the amino acid stage. Examples are the pepsin of gastric juice and the trypsin of pancreatic juice.

It should be remarked that all the above enzymes act by hydrolysis, and at body temperature.

The following is a list of some of the alimentary enzymes:—

Enzyme	Source	Substrate	End products
Polysaccharidases —			
Ptyalin	Saliva	Starch	Dextrins + maltose.
Amylase	Pancreas	Starch	Maltose.
Saccharidases —			
Maltase	Intestine	Maltose	Glucose + glucose.
Sucrase	Intestine	Sucrose	Glucose + fructose.
Lactase	Intestine	Lactose	Glucose + galactose.
Esterases (lipases) —			
Lipase	Stomach	Fat	Fatty acid + glycerol.
Lipase	Pancreas		
Lipase	Intestine		
Proteinases —			
Pepsin	Stomach	Protein	Peptones.
Trypsin	Pancreas	Protein	Peptones + amino acids.
Erepsin	Intestine	Peptones	Amino acids.

SUMMARY

DIGESTION—processes which reduce food to an absorbable condition.

1. **Mechanical**—mastication, deglutition, peristalsis.
2. **Chemical**—hydrolysis by enzymes.
3. **Control of digestion and co-ordination with rest of body**:—
 - (a) **Nervous**—Parasympathetic—augmentory and secretory.
Sympathetic—inhibitory and vaso-constrictor.
 - (b) **Chemical**—by autogenous substances (autacoids).

ENZYMES—alter rate (velocity) of chemical reactions—mostly accelerate.

Substrate—the medium upon which an enzyme acts (adsorption).

Modes of action—mostly hydrolysis, some by oxidation or reduction.

Properties—specific, inactivated by heat, work best at an optimum temperature and reaction, reversible.

Classification—based on nature of substrate.

- (a) Polysaccharidases (amylases)—convert starches to maltose.
- (b) Saccharidases—convert disaccharides to monosaccharides.
- (c) Esterases (lipases)—convert fats to fatty acid and glycerol.
- (d) Proteinases—convert proteins to amino acids.

CHAPTER XVII

DIGESTION—THE TEETH AND MASTICATION

TEETH are epidermal structures found in most vertebrates, though some are edentulous. There are great variations in their shape, number and distribution. In fishes they are all alike (homodont), while in addition the dogfish has them all over its skin (placoid scales), and the frog has teeth in the roof of its mouth (vomerine teeth), in the upper jaw (maxillary teeth), but none in the lower jaw. In some animals the teeth are constantly renewed throughout life. Birds have no teeth.

Each tooth has a *crown*, a *neck* and a *root* consisting of one or more *fangs*. The *crown* is the part which protrudes beyond the gum into the mouth. The *neck* is that slightly constricted portion which is embraced by the gum ; and the *fang* or *fangs* include all that part of the tooth which penetrates into the jaw-bone. Teeth assist in speech, but their primary function is to work with the jaws. These latter are prehensile, while the teeth are comminutive, *i.e.* the jaws seize the food, which the teeth then proceed to tear and grind.

If we examine our teeth we shall notice that they vary much in general form as in most mammals. It is for this reason they are described as **heterodont** (Gr. *heteros*, different ; *odous*, a tooth). The central four of each jaw are provided with sharp, chisel-like edges, and are consequently well adapted for biting or cutting : these are called the **incisors**, central and lateral. The upper incisors are larger and stronger than the lower ones. Next to these, on each side, is a single tooth of about the same size, which has a somewhat pointed crown. This is called the **canine** or **dog tooth** (Lat. *canis*, a dog), because its position in the human skull corresponds with that of the long, conical, tearing tooth in the skull of the dog and other carnivorous (Lat. *caro*, flesh ; *voro*, I devour) or flesh-eating animals. The human canine tooth may also be said to slightly resemble that of a carnivorous animal in general form, inasmuch as its summit is more or less conical. They are larger and stronger than the incisors and they have very deep roots which cause well-

marked prominences on the superior maxillæ. The upper canines are popularly called the eye-teeth. They are usually a little larger and longer than the lower. Beyond these canine teeth is a pair of **premolars** or **bicuspid**s (Lat. *bis*, twice; *cuspis*, a pointed extremity), so called because each has two cusps or ridges on the top of the crown, separated by a furrow. Behind these again are larger teeth, each possessing two or more

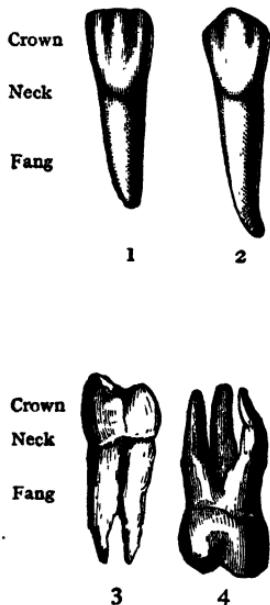


Fig. 83.—Showing the four kinds of Human Teeth.

1, incisor tooth (external view); 2, canine tooth (external view); 3, bicuspid tooth (side view showing the two cusps); 4, an upper molar tooth (external view).

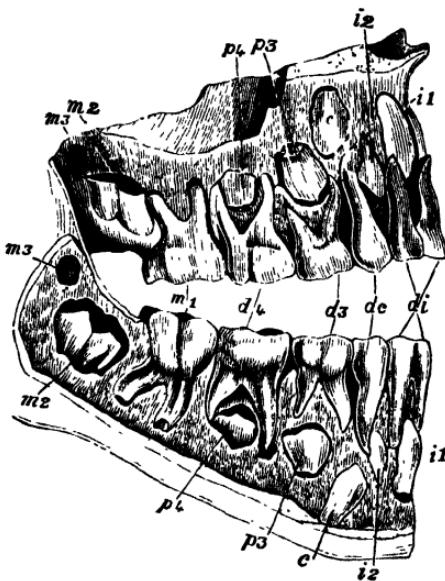


Fig. 84.—Section of the Jaws of a Child of 6½ Years, showing the Milk of Deciduous Teeth, also the Permanent Teeth in Process of Formation.

d1, the milk incisors; *dc*, the milk canines; *d3* and *d4*, the milk molars; *i1* and *i2*, the permanent incisors; *c*, the permanent canines; *p3* and *p4*, the permanent bicuspids; *m1*, the first permanent molars, which have already made their appearance; *m2* and *m3*, the second and third permanent molars.

fangs, and having a very broad and irregular surface well adapted for the grinding of food; hence these teeth are called the **molars** (Lat. *mola*, a mill).

Usually the first molar is the largest and the third the smallest. Each upper molar has three roots, each lower one two roots. The three roots of each upper molar are arranged two on the buccal (cheek) side and one on the lingual (tongue) side; while

in the case of the lower molars, one root is anterior and the other posterior. The roots fit into corresponding sockets in the jaws. This enables them to be extracted, if occasion requires. In some animals, e.g. the frog, the teeth are **fused** into the jaw (upper), which would render extraction almost impossible.

DECIDUOUS TEETH.—Some animals have two or more sets of teeth. Man has two sets, the first of which is known as the **milk, temporary** or **deciduous** teeth (Lat. *deciduus*, falling). These consist of four *incisors* in the front of each jaw, a single *canine* tooth on each side of these, and a pair of *molars* on each side beyond the canines. They are smaller, whiter, but otherwise similar to the permanent set. The largest of all is the hinder of the two molars. The roots of the milk teeth are smaller and more divergent than those of the permanent set. A child of about six years should possess twenty milk teeth. At the age of about seven years these milk teeth begin to be cast off, their places being taken by the **permanent teeth** which grow beneath them; and, at about the age of twelve, all have in this way given place to the permanent set.

Note that the milk molars of a child are replaced by the premolars of the adult, while the adult molars have no predecessors. Rickets is a disease which delays the appearance of the teeth. Also when the teeth do appear they have defective enamel and soon wear away.

THE ERUPTION OF TEETH.—As the teeth in the young baby calcify, the tooth makes its way upwards through the gum, which latter gradually gets absorbed. The first teeth erupt at about the sixth or seventh month, and the whole set is complete at the end of the second year. The lower central incisors come first, then the upper, next the lower lateral incisors, first molars and canines; and lastly, the second molars. The teeth of the lower jaw usually precede the corresponding ones of the upper jaw.

THE PERMANENT TEETH of the adult number thirty-two. They consist, in each jaw, of four *incisors*, two *canines*, four *bicuspid* or premolars, and six *molars*. The last of the molars are called the **wisdom teeth**; they do not appear till between the seventeenth and twenty-fifth years, and sometimes still later.

In the permanent teeth the first molar appears first, at the sixth year, then the central and lateral incisors and the canines. The premolars appear at the ninth to tenth years, the second

molar at the end of the twelfth year, and the third molar as stated above.

THE STRUCTURE OF A TOOTH.—The mass of a tooth consists chiefly of a hard substance called **ivory** or **dentine** (Lat. *dens*, a tooth). It resembles in composition the compact tissue of bone, but contains a much larger proportion of mineral matter (72 per cent.), and is consequently harder. The mineral matter, like that in bone, consists chiefly of calcium

phosphate and calcium carbonate ; and the animal matter may also be made to yield gelatine by boiling. In structure dentine differs from bone, as it contains no Haversian canals, lacunæ, etc., but is penetrated by a multitude of very delicate tubes (the **dental canaliculi**) which communicate with the cavity of the tooth.

This cavity is called the **pulp-cavity**. It contains a very soft substance—the **pulp**. This consists of a mass of minute blood-vessels, nerves and connective tissue which enter through an opening at the apex of each fang.

The dentine which forms the crown of the tooth is covered with a substance called the **enamel**. It forms a thin crust over the crown as far as the commencement of the root. It is the hardest substance in the body, and contains only 2 or 3 per cent. of animal matter. When examined under a high magnifying power the enamel is seen to consist of exceedingly fine hexagonal prisms, set vertically to the dentine.

Fig. 85.—The Lower Right Half Jaw, showing its Eight Permanent Teeth.
1, the incisors; 2, the canine;
3, the premolars; 4, the molars.

cally to the dentine.

The root of each tooth is surrounded by a substance called the **cement**. This substance is softer than the dentine, and in structure and composition resembles bone—it contains *lacunæ* and *canalliculi*, but no Haversian canals. The cement extends from the apex of the root to the place where the enamel ends. It is covered with dental periosteum, which also lines the socket, and helps to hold the tooth in position.

DENTAL FORMULÆ are a useful means of indicating at a glance the number and distribution of the teeth in one half of each jaw. Thus in the case of our permanent teeth we may concisely represent the facts by the formula $\frac{2.1.2.3}{2.1.2.3}$. If we are referring to the milk teeth the formula is $\frac{2.1.2.0}{2.1.2.0}$.

In the case of the rabbit the formula is $\frac{2.0.2.3}{1.0.2.3}$, so that he has a gap in the canine region, known as a **diastema** (Gr. an interval). Ruminants are represented by $\frac{0.0.3.3}{3.1.3.3}$, and the dog by $\frac{3.1.4.2}{3.1.4.3}$.

In discussions and writings concerning the teeth it is usual to consider that one is facing the patient, so that a graphical representation of the teeth may be made thus:—

	Right.		Left.	
Deciduous teeth (20)	E D . C . B A E D . C . B A		A B . C . D E A B . C . D E	Upper Lower
Permanent teeth (32)	8 7 6 . 5 4 . 3 . 2 1 8 7 6 . 5 4 . 3 . 2 1		1 2 . 3 . 4 5 . 6 7 8 1 2 . 3 . 4 5 . 6 7 8	Upper Lower

With this as a basis one may readily designate any particular tooth in a very simple manner. Thus B means the lateral right upper incisor of the milk teeth, while 3 means the lower left canine of the permanent teeth, and 8 the lower right wisdom tooth.

THE USE OF TEETH is to masticate the food, that is, to reduce it to such a finely divided state that it may be readily acted on by the various digestive fluids. It has already been noticed that the different kinds of teeth are adapted for different modes of action; and we may now observe how this variety of action is still further increased by the complex movement of the lower jaw. When we bite our food we move the jaw perpendicularly, and make use of the front or incisor teeth. After this it is passed over to the molars, which thoroughly crush and grind it. Now, this grinding could not be carried on effectually if the lower jaw were capable of a vertical motion only. But if we observe the motion of the jaw during the grinding of the food we shall find that it moves a little to the right and left, and also forward and backward. The broad and rough surfaces of the molar teeth are consequently caused to slide over each other, thus thoroughly grinding the food which may be between them.

It will be noticed that in biting we use the mandible (lower jaw) as a lever of the third class. The resistance offered by the object bitten forms the weight, while the skull forms the fulcrum. The power is formed by muscular action applied between the weight and fulcrum. The *carnivorous animals* have not broad molars like ours. They bite and tear the flesh on which they feed, generally giving the jaw an up-and-down motion only. The *herbivorous animals*, on the other hand, have very large and perfect molars, and they give to the lower jaw a much greater variety of motion than we do. This may be readily observed in the cow, sheep, goat and horse.

Apart from their use in mastication, teeth, among the various vertebrates, serve other useful purposes—the tusks of elephants for protection, and the fang of the snake for offence.

THE MUSCLES OF MASTICATION are :—The **masseter**, **temporalis** and the **internal pterygoid**, which raise the lower jaw (mandible) against the upper one (maxilla). There is also the **external pterygoid** which protrudes the mandible. These muscles are all supplied by the inferior maxillary nerve—the third division of the fifth cranial nerve (trigeminal nerve).

During mastication the food must be continually moved about so that every portion of it may be brought between the molar teeth. This is effected by the muscles of the tongue, cheeks and lips.

SUMMARY

DENTAL FORMULÆ—show number and distribution in each half jaw.

Man (a)	$\frac{2.1.2.0}{2.1.2.0} \rightarrow 20$	Man (b)	$\frac{2.1.2.3}{2.1.2.3} \rightarrow 32$
(Deciduous)		(Permanent)	
Dog	$\frac{3.1.4.2}{3.1.4.3} \rightarrow 42$	Rabbit	$\frac{2.0.3.3}{1.0.2.3} \rightarrow 28$

STRUCTURE OF A TOOTH.

Enamel	<table border="0"> <tr> <td>The exposed outer portion, covering the crown.</td></tr> <tr> <td>Hardest substance in body—2 per cent. animal matter.</td></tr> <tr> <td>Composed of elongated hexagonal prisms.</td></tr> </table>	The exposed outer portion, covering the crown.	Hardest substance in body—2 per cent. animal matter.	Composed of elongated hexagonal prisms.
The exposed outer portion, covering the crown.				
Hardest substance in body—2 per cent. animal matter.				
Composed of elongated hexagonal prisms.				
Dentine	<table border="0"> <tr> <td>Forms greater portion of tooth—dentine tubules.</td></tr> <tr> <td>Harder than bone—72 per cent. mineral matter.</td></tr> <tr> <td>Well supplied with sensory nerves (pain).</td></tr> </table>	Forms greater portion of tooth—dentine tubules.	Harder than bone—72 per cent. mineral matter.	Well supplied with sensory nerves (pain).
Forms greater portion of tooth—dentine tubules.				
Harder than bone—72 per cent. mineral matter.				
Well supplied with sensory nerves (pain).				
Cement	<table border="0"> <tr> <td>Surrounds dentine below level of gums.</td></tr> <tr> <td>Is true bone, with lacunæ and canaliculi</td></tr> <tr> <td>Covered with dental periosteum, which also lines socket.</td></tr> </table>	Surrounds dentine below level of gums.	Is true bone, with lacunæ and canaliculi	Covered with dental periosteum, which also lines socket.
Surrounds dentine below level of gums.				
Is true bone, with lacunæ and canaliculi				
Covered with dental periosteum, which also lines socket.				

Pulp cavity { Filled with nerves, connective tissue, blood-vessels.
Foramen at apex of fangs for nerves and blood-vessels.

FUNCTIONS—prehension, comminution, speech (in man).
Toads, turtles, tortoises and birds are edentulous.

MASTICATION—the reduction of food to a soft pulpy mass.

Biting—by incisors and canines, } jaws moved vertically.
Chewing—by premolars and molars, } aided by muscles of tongue,
 } jaws moved horizontally. lips, cheeks.

Muscles—temporalis, masseter, internal and external pterygoides.

CHAPTER XVIII

GLANDS—THE SALIVARY GLANDS

A GLAND is an organ which separates or forms certain materials from the blood circulating through it.

THE CLASSIFICATION OF GLANDS may be made in several ways, depending on their histological structure, or the nature of their products. It was originally considered that the possession of a duct was an essential part of a gland, until other structures were found which were almost certainly glandular, and yet had no ducts. On this historical basis we have the following scheme of classification :—

1. **EXOCRINE GLANDS** (Gr. *ex*, out ; *crino*, I separate) —those which have a duct to carry off the products of their activity. These are usually subdivided into secreting and excreting glands, though the distinction is not always clear, and, indeed, some organs may act in both ways.

(a) **A secreting gland** (Lat. *se*, aside ; *cerno*, I separate) is one which prepares a substance from the materials of the blood, in which the substance did not pre-exist. The salivary glands and the pancreas are familiar examples of this type.

(b) **An excreting gland** is one which separates material from the blood, afterwards to be cast from the body. Examples are the sweat glands of the skin and the kidneys.

In both these cases there is a well-recognised duct present which carries away the gland products. The gland is also well supplied with blood-vessels and nerves to control the production. In some cases there may also be a bag or bladder to (temporarily) hold the fluid, such as the gall bladder and urinary bladder.

2. **ENDOCRINE GLANDS (ORGANS)** (Gr. *endon*, within) are those which have no duct to carry off their products, which pass at once into the blood or lymph vessels. Examples are the thyroid, pituitary, suprarenals and thymus. All these will be considered in Chap. XXXVIII.

It must be borne in mind that the above classification is not at all satisfactory. Thus, the pancreas is both an exocrine and an endocrine organ, the liver is secretory and excretory. To add

to this it is now known that when a nerve is stimulated there is a substance freed at its ends which serves for the chemical transmission of the impulse—acetyl choline in some cases and adrenaline in others. We may call this a neurocrine secretion. Lastly, the gonads and lymphatic glands present yet another

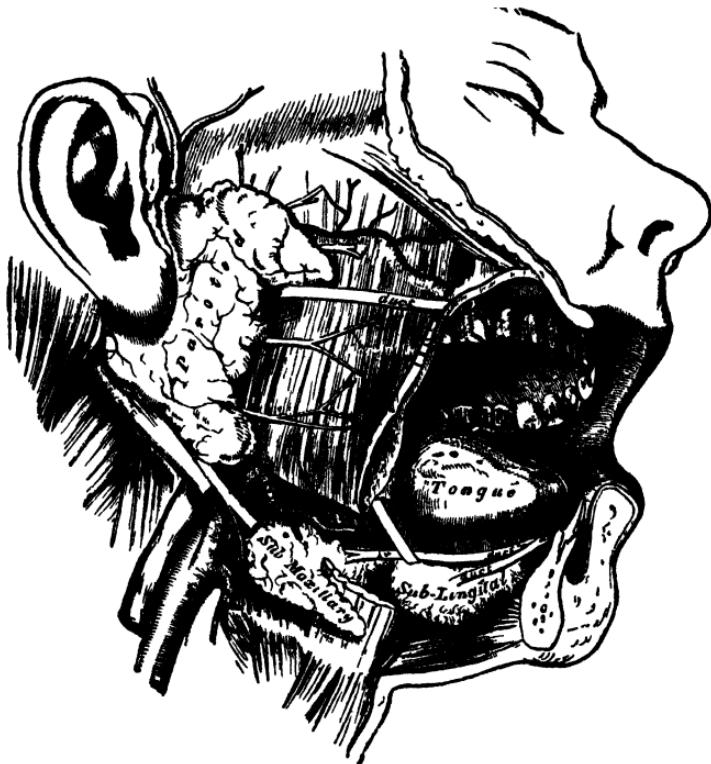


Fig. 86.—The Salivary Glands.

The right side of the lower jaw has been removed, and the face dissected, in order to show the three salivary glands of the right side

difficulty, for their product is *living cells* and not a fluid, *i.e.* they are cytocrine.

THE SALIVARY GLANDS are three large masses of secretory tissue lying within the oval cavity on each side, known as the **parotid**, the **submaxillary** and the **sublingual**.

1. **The parotid glands** (Gr. *para*, near; and *ous*, the ear) are situated below and in front of the ear. They are the largest of the salivary glands. Their ducts are known as Stensen's

ducts, and open into the mouth through the cheek, just opposite the second molar teeth of the upper jaw. The parotid secretion is said to be "serous," i.e. it is a watery non-viscid saliva. This gland has a double nerve supply. The secretory fibres are parasympathetic and come from the glosso-pharyngeal or ninth cranial nerve, while the sympathetic supply is vaso-constrictor.

2. **The submaxillary glands** (Lat. *sub*, under; *maxilla*, a jaw) are about the size of a small walnut. They are situated beneath the lower jaw, one on each side. The ducts of these glands, known as Wharton's ducts, open into the mouth under the tip of the tongue, at the side of the frenulum or bridle which binds the tongue down to the floor of the mouth. They may be easily seen by means of a looking-glass.

The submaxillary and sublingual glands have also a double nerve supply:—

(a) **Parasympathetic fibres** via the chorda tympani branch of the seventh cranial nerve. Its action is to cause vaso-dilation and salivary secretion.

(b) **Sympathetic fibres**, which produce vaso-constriction. Their secretory action is not yet understood.

3. **The sublingual glands** (Lat. *sub*, under; *lingua*, tongue) are no larger than almonds, are situated on each side of the bridle, forming ridges between the tongue and the gums of the lower jaw, and are covered only by mucous membrane. Each of these glands has several ducts, which open into the floor of the mouth. The secretions from the submaxillary and sublingual glands are viscid and so said to be a mucous saliva.

THE SALIVA is the mixed (i.e. serous and mucous) fluid secreted by the salivary glands, a cloudy, somewhat slimy, watery fluid, slightly alkaline in action, and of specific gravity 1005. It consists of more than 99 per cent. water, the rest being mineral salts and organic matter.

It should, however, be pointed out that the secretions of the salivary glands differ slightly in their composition. The submaxillary and sublingual glands give a viscous secretion due to mucin, but there is none in the parotid secretion. Hence we call the parotid a **serous** salivary gland, while the other two are **mixed** glands, for they contain both serous and mucous portions.

Ptyalin (Gr. *ptuo*, I spit) is an enzyme, and may be described as the active principle of the saliva, for the value of the latter as a digestive fluid depends on its presence.

CHAPTER XIX

THE œSOPHAGUS AND DEGLUTITION. THE STOMACH AND GASTRIC DIGESTION

THE œSOPHAGUS is that portion of the alimentary canal lying between the pharynx and the stomach. It is about 25 cms. long, and is the narrowest portion of the alimentary passage. It is essentially a muscular tube which consists of four distinct coats :—

1. The external coat is merely a fibrous communication with the surrounding tissues.
2. A thick *muscular* coat composed of two distinct sets of muscular fibres, an outer running longitudinally down the tube, and an inner passing in a circular direction round it.
3. An *areolar* or *submucous* coat. It consists of loose areolar tissue with its blood-vessels, nerves and lymphatics, which unites the muscular and mucous coats of the tube. Its texture is purposely loose to accommodate the varying calibre of the œsophagus.
4. The inner coat is a *mucous membrane*, which, as its name implies, contain mucous glands. It is covered with a thick layer of stratified squamous epithelium into which papillæ project from the deeper layers. It is drawn up into longitudinal folds, thus increasing the amount of secreting surface, and also allowing for dilatation as the bolus of food passes along it. Except for the pylorus it is the narrowest part of the alimentary canal.

DEGLUTITION.—It is usual, but really quite arbitrary, to divide the act of swallowing into three (continuous) stages :—

Stage 1 is voluntary.—After the food has been masticated and thoroughly mixed with the saliva, it is collected into a bolus by the tongue and the muscles of the cheeks, and then passed between the tongue and the palate till it reaches the back of the mouth. This muscular action may be voluntary, but is usually performed subconsciously.

Stage 2.—The food must now pass into the pharynx without touching the posterior nares or entering the glottis. This is

accomplished as follows : The *larynx* and *pharynx* are both raised together and carried forward under the tongue. The *glottis* is closed by the *epiglottis*; and the *posterior nares* are shut off by the sides of the soft palate. The contraction of the muscles at the back of the mouth forces the food over the epiglottis into the pharynx. The pharynx now contracts above it, and the bolus is forced into the *œsophagus*.

Stage 3.—As soon as the food enters the upper portion of the œsophagus the circular muscles in the walls of that tube contract just above it, thus forcing it a little downward. This action is repeated by all the circular muscular fibres throughout the tube, each set contracting *just behind the food* and relaxing in front, until it passes into the stomach. It must not be understood, however, that the food is forced down the œsophagus by a series of distinct movements or jerks ; but that the successive muscular contractions produce a regular wavelike motion throughout the tube. It should be mentioned that the upper musculature of the œsophagus is of the voluntary type, while the lower portion is composed of plain or involuntary muscle.

It will have been observed that the act of swallowing is a reflex muscular action—that the food does not *fall* into the stomach by its own weight, but is *forced* downward. This being the case, the act of swallowing may be performed with the body in any position. Thus some jugglers can eat while standing on their heads. Horses drink against gravity, but birds seem to require its aid.

After the food has passed to the back of the mouth, the remainder of the act of *swallowing* or *deglutition* (Lat. *de*, down ; and *glutio*, I swallow) is purely involuntary, and consequently we cannot then stop the bolus in its passage to the stomach. The *mucus* secreted by the mucous cells in the submucous coat of the œsophagus, and also from the submaxillary and sub-lingual glands, acts as a *lubricant*, and thus facilitates the passage of the food.

THE NERVOUS MECHANISM OF DEGLUTITION.—Swallowing is a reflex—it can be seen in patients who are anaesthetised. The bolus stimulates branches of the superior laryngeal branch of the tenth cranial nerve which supply the epiglottis, the ninth nerve supplying the tongue and pharynx, and the second division of the fifth nerve supplying the palate and tongue. The centre lies in the medulla oblongata. The efferent motor nerves concerned are several—the twelfth to the tongue, the fifth to the mylohyoid muscle, while the tenth and eleventh supply the muscles of the pharynx.

When the oesophagus is not engaged in swallowing it is flattened, its front and back walls being in contact. In order that the act of deglutition may take place with regularity and ease the bolus of food must be sufficiently large to be within the grasp of the contracting muscles. It is on this account that some persons experience a considerable difficulty in swallowing a pill, especially if it be a small one, unless food or drink be taken at the same time.

Relation between Deglutition and Respiration.—It is evident that if one is to swallow food, respiration must cease for the time, and conversely one cannot breathe and swallow simultaneously, or choking is inevitable and may be serious—leading to aspiration pneumonia. To guard against this we have another reflex act. The mere stimulation of the ninth nerve as occurs naturally during swallowing inhibits all respiration, and this no matter in what stage it may be. The cessation lasts sufficiently long for complete deglutition.

THE STOMACH.—

The general form, size and position of the **stomach** have already been described; we have now to notice the structure of its walls, and its action on the food.

The **walls of the stomach** consist of four distinct coats. The **outer coat** is a layer of the peritoneum which covers the whole surface except along the greater and lesser curvatures, *i.e.* at the points of attachment of the greater and lesser omenta. It is a **serous membrane**, that is, one which secretes a watery fluid whose purpose is to moisten or lubricate the surfaces of organs which glide more or less over each other.

The other three coats of the stomach correspond exactly with those of the oesophagus, and are, in fact, continuations of

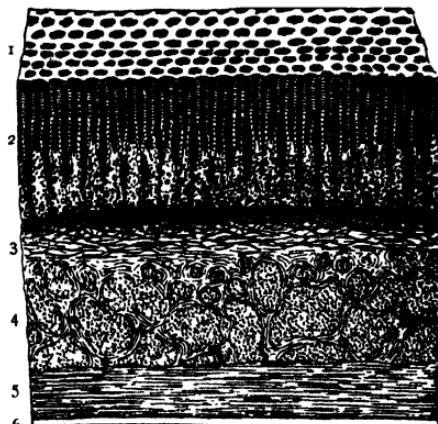


Fig. 87.—A Section through the Walls of the Stomach. ($\times 15$.)

1, surface of the mucous membrane, showing the openings of the peptic glands; 2, mucous membrane, composed almost entirely of glands; 3, submucous or areolar tissue; 4, transverse muscular fibres; 5, longitudinal muscular fibres; 6, peritoneal coat.

them. The outer of these, which, of course, lies next the peritoneal coat, is **muscular**; the next is composed of **areolar tissue**, and the inner coat is a **mucous membrane**. This arrangement is common to the whole of the alimentary tract.

The stomach is divided physiologically into three portions, the cardiac (fundus), body and pyloric parts. It is only the distal or pyloric part which undergoes rhythmical movement or peristalsis. The function of the body is merely to exert a constant pressure on the contents and to act as a reservoir.

The walls of the stomach are capable of great distension; consequently it can adapt itself to the quantity of food it con-

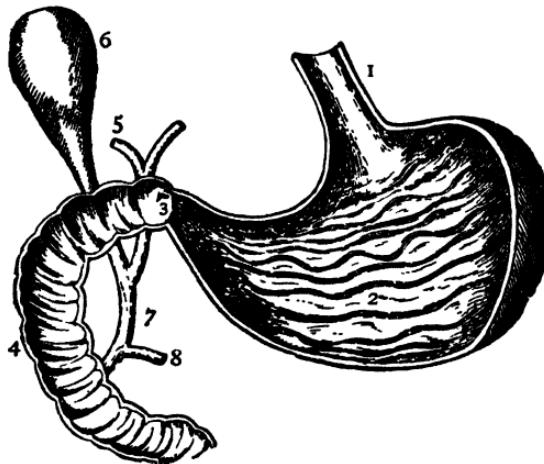


Fig. 88.—The Stomach and the Duodenum, laid open to show the Mucous Membrane.

1, oesophagus ; 2, mucous membrane of the stomach ; 3, pylorus ; 4, duodenum ; 5, the ducts which convey the bile from the liver ; 6, gall-bladder ; 7, common duct ; 8, the pancreatic duct.

tains, and, at the same time, be always in contact with the food so as to act on it. Hence we may say that the expansion of the stomach is such that the intragastric pressure is not increased, or, as the dilatation increases the pressure on the contents remains the same.

The circular muscular fibres at the intestinal end of the stomach form a strong band which serves to keep it closed. Such circular muscles are called **sphincters** (Gr. *sphiggo*, I bind). In the case of the stomach it is known as the **pylorus**. This sphincter remains at first firmly closed during digestion; but, as the process continues, it relaxes at certain intervals, thus

allowing the digested portions to be ejected into the intestines ; and, towards the termination, it allows *all* the contents of the stomach to pass. Other examples of sphincters will be met with later—the iris, the neck of the bladder and the *anus*.

The time during which substances remain in the stomach varies considerably with the nature of the food and the method of cooking. Usually it is not less than one hour, and seldom more than four hours.

The **mucous membrane of the stomach** is smooth, level and soft, when the organ is moderately distended ; but is drawn up into longitudinal folds when the stomach is empty. It is covered with columnar goblet cells which secrete **mucus** to keep the surface **moist**, and its thickness is due to the fact that it is made up of long tubular glands, the **gastric glands** whose function is to secrete the **gastric juice**.

They are called **peptic glands** (Gr. *pepto*, I cook, or digest), and are tubular. The openings of these may be seen on the surface of the mucous membrane by the aid of a lens. As fig. 89 shows, there are three types of cell present : the columnar goblet cells which yield mucus, the columnar cells lining the gland and forming the main bulk of the gastric juice, especially the pepsin, and the deeply staining outer or oxyntic cells which secrete the hydrochloric acid.

When the stomach contains no food, the mucous membrane is very pale in colour, and is moistened by mucus and saliva. As soon as food, or even a non-digestible substance, is introduced, the supply of blood increases, the mucous membrane becomes of a bright pink colour, and the secretion of the gastric fluid immediately commences.



Fig. 89.—Peptic Gland from the Mucous Membrane of the Stomach. Highly magnified.

Note the three types of cell present—goblet, oxyntic and peptic.

It is difficult to ascertain accurately the quantity of gastric fluid secreted in a given time, but after careful experiments and observations it has been estimated that as much as 500 c.c. are poured into the stomach after a good meal.

The **gastric fluid** is a clear and colourless liquid, having a slightly saltish and acid taste. It is mostly water—over 99 per cent. The rest is pepsin, rennin, mucin, with about 0.4 per cent. free HCl.

THE ACTIONS OF GASTRIC JUICE.—Pepsin is the active principle of the gastric fluid. It is an enzyme which has the power, in the presence of hydrochloric acid, of digesting nitrogenous or protein foods. Hence pepsin is known as a proteolytic enzyme.

Gastric juice produces yet other changes in the food. The HCl hydrolyses cane sugar to glucose and fructose, it precipitates the caseinogen, and causes collagen to swell up. The pepsin (or rennin) in the presence of calcium salts converts caseinogen into solid casein, i.e. it clots milk. The curd is then still further acted on by the gastric juice and reduced to peptone. Starch foods are dissolved in the stomach by the swallowed saliva, but the acidity of the gastric juice soon retards and ultimately stops this action. Fatty tissue consists of fat cells united together by areolar tissue, and each cell consists of a particle of fat surrounded by a cell-wall of albuminous (nitrogenous) substance. Consequently, when fatty tissue passes into the stomach, the areolar tissue and the albuminous cell-walls are dissolved, and the fat itself is set free as minute globules.

The semi-digested contents of the stomach are called **chyme** (Gr. *cheo*, I pour), because it is poured into the intestine. It consists of—

- (a) Saliva and partially dissolved starchy foods in various stages from that of starch to that of maltose, glucose and fructose.
- (b) Gastric fluid and partially dissolved nitrogenous foods in various stages from protein down to peptone.
- (c) Undigested fat in the form of minute globules.
- (d) Mucus from the mucous glands in inner coat of stomach.
- (e) Indigestible substances, especially cellulose.

The character of the chyme varies considerably according to the nature of the food taken; but it is generally a thick, milky, acid fluid, possessing a disagreeable odour. It causes the outpouring of bile, and of secretin, and stimulates the duodenum to peristalsis.

The average time occupied in producing this change in the stomach contents is about three hours.

Fractional Test Meals.—The information we possess concerning these changes in the stomach is the result of a number of observations made in various ways. The Abbé Spallanzani (1729-99) investigated digestion, both in animals and man, by causing them to swallow sponges tied to a string. The sponge could be withdrawn and its contents squeezed out and analysed. During the life of an animal gastric juice may be obtained by means of a fistula. In the case of a human being it may be obtained by administering a standard gruel meal. Then one withdraws small samples at 15-minute intervals from a tube which has been swallowed till its end lies in the chyme. This is known as a "fractional test meal," and is a routine procedure at hospitals in dealing with patients having gastric complaints (ulcers).

THE MOVEMENTS OF THE STOMACH are studied in anaesthetised animals by direct observation on opening the abdomen, or in man by means of the X-rays. Peristaltic waves are seen in the pyloric part, especially the antrum, gradually pushing the food onwards. All gastric movements are, of course, co-ordinated—when the cardiac end opens the body relaxes to accommodate the food, and when the pylorus relaxes the antrum contracts. The stomach wall possesses its own power of automatic rhythmicity independent of the central nervous system, but the pylorus is dependent on the nervous system.

Radiography of the gastro-intestinal tract.—A great deal of information relative to the size, shape, time and degree of emptying of the stomach is now obtained by the use of X-rays. The patient is given food (bread and milk or porridge impregnated with BaSO₄). This produces a dark shadow when seen by aid of the X-rays. Hence the movements of the stomach can be followed, and also the passage of the food along the alimentary canal. Imperfections in the times of emptying, and the presence of growths and ulcers, may thus be detected.

Absorption in the Stomach.—The soluble and diffusible substances formed by the action of the gastric fluid on nitrogenous foods are called peptones. Very little absorption occurs in the stomach—only a little alcohol, glucose and a few drugs. Water is not absorbed, but since alcohol is, this may be the cause of the rapidity of intoxicating action of the latter on an empty stomach. Absorption really only begins in the duodenum.

Vomiting or emesis is the rejection of the stomach contents *via* the oesophagus and mouth. It may be produced by a variety of causes—overdistension, irritant food, or reflexly from

other organs, such as the uterus (when it contains a foetus), gall-bladder (gallstones), disease of the cerebrum, by tickling the back of the throat, and by psychological means. It is mainly due to the contractions of the diaphragm and abdominal muscles, between which the stomach is compressed, the pylorus being firmly closed, and the cardiac orifice and oesophagus relaxed. Drugs, such as ipecacuanha, $ZnSO_4$, and tartar emetic, produce vomiting by gastric irritation, while apomorphine directly stimulates the vomiting centre in the medulla.

SUMMARY

ŒSOPHAGUS (food pipe)—muscular tube, connects pharynx and stomach.

Deglutition—reflex, involuntary peristaltic waves.

Involves muscles of mouth, pharynx, œsophagus.

STOMACH—muscular glandular bag. Holds food, partly digests proteins.

Coats	Outer serous layer of peritoneum.
	Muscular—in three layers, for peristalsis.
	Submucous—areolar, for blood-vessels and nerves.

Mucous—glandular (pepsin, HCl, mucus).

Movements—Peristaltic waves in pyloric part.

GASTRIC JUICE—the combined secretions of the gastric glands.

Composition—0·4 per cent. free HCl, pepsin (rennin), 99 per cent. water.

Actions	Proteoclastic—hydrolyses proteins to peptones.
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Actions	Coagulative—caseinogen of milk converted to casein.
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Actions	Lipoclastic—hydrolyses fats.
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Actions	HCl hydrolyses sucrose to glucose and fructose.
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Mechanism of secretion.

a. Nervous—sight of food, psychic, act of mastication.

b. Chemical—pyloric gastrin stimulates glands (?).

Histamine (in meat extracts) and dextrin also stimulate.

CHAPTER XX

THE INTESTINES, PANCREAS AND LIVER. INTESTINAL DIGESTION

GENERAL STRUCTURE OF THE INTESTINES

—This, like the stomach, and indeed the whole of the alimentary tract, consists of **four coats**. These coats also correspond with those of the stomach, being arranged as follows :—

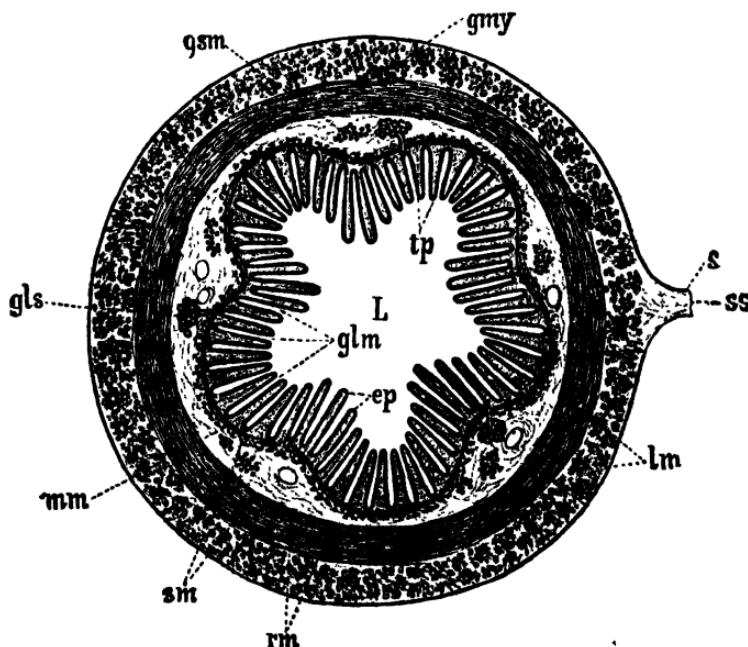


Fig. 90.—Diagrammatic Section of the Alimentary Canal.

L, lumen; gim, intestinal glands (not villi); ep, epithelium; gls, Brünner's glands in submucosa; mm, muscularis mucosae; sm, submucous coat; im, inner circular muscular layer; lm, outer longitudinal muscular layer; s, outer serous coat; ss, mesentery; gmy, ganglia of Auerbach's plexus; gsm, ganglia of Meissner's plexus.

1. **An outer serous coat**, formed by the peritoneum (mesentery). Its function is twofold: (a) To hold up the intestines. (b) To convey vessels and nerves to the gut wall.

2. **A muscular coat**, composed of external fibres arranged longitudinally, and a set of internal fibres arranged circularly.

3. **A submucous coat of areolar tissue**, in which the blood-vessels, nerves and lacteals ramify.

4. **Inner mucous membrane**, lined by columnar epithelium, and containing countless small glands. This membrane is in part drawn up into folds, like that of the stomach, but to such

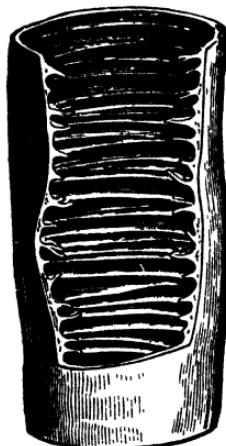


Fig. 91.—A Portion of the Small Intestine laid open to show the Folds of the Mucous Membrane (*Valvulae conniventes*).

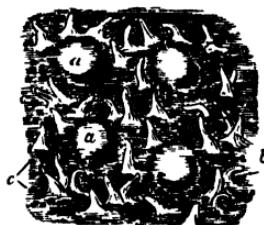


Fig. 92.—A Small Portion of the Mucous Membrane of the Small Intestine. ($\times 12$.)

a, Peyer's glands, surrounded by tubular glands; b, villi; c, openings of the tubular glands. The villi are just visible to the naked eye, when examining a patch of the small intestine.

an extent that they do not disappear when the tube is distended. These permanent folds are the **valvulae conniventes**. They serve to increase the area of the secreting surface, to prevent the food from passing too rapidly through the intestine, and to assist the mixing of the food with the digestive fluids which are poured into the intestines.

The mucous coat of both large and small intestines also resembles that of the stomach in that it consists chiefly of glands, but they are different in histological structure.

THE GLANDS are of various kinds; some are tubular, and arranged parallel with each other. These are known as the

crypts of Lieberkuhn. Others (Peyer's glands) are somewhat globular or ovoid in form, and are distributed singly (solitary) or in groups (Peyer's patches). They consist of nodules of lymphoid tissue and found chiefly in the ileum. Others, again, are minutely lobulated (Brünnner's glands), just visible to the naked eye. They are only found in the submucous coat of the duodenum, and hence are characteristic of it.

The ducts of these glands (excepting the lymphoid tissue, which has no ducts) open on the internal surface of the intestines and thus pour their secretions into the alimentary canal.

THE SUCCUS ENTERICUS.—The nature of the secretions of these glands is difficult to investigate. Some

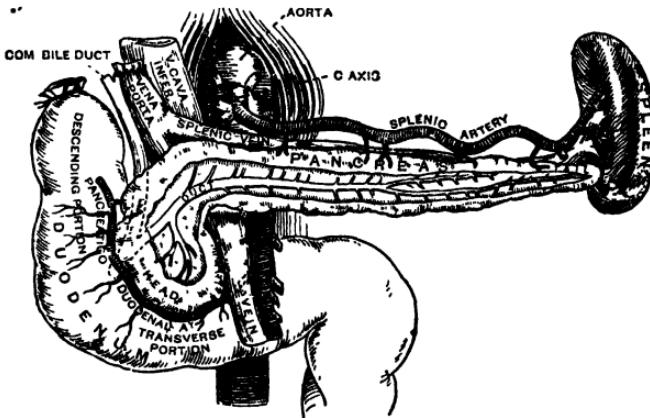


Fig. 93.—The Duodenum, Spleen and Pancreas.

of them probably secrete mucus only; others resemble the salivary glands and the pancreas in function.

The collected secretions of all these glands is known as the **succus entericus**. It is an alkaline fluid. The essential constituents, however, are several ferments whose function is to complete the digestion of all classes of food substances:—

1. **Saccharidases**, such as **invertase**, which hydrolyses cane sugar (sucrose) to glucose and lactose; **lactase** which changes lactose into glucose and galactose; and **maltase** which converts maltose to glucose.

2. **Erepsin** is a peptidase which acts on peptones and reduces them to amino acids.

3. **Enterokinase** which appears to be needed to act on the trypsinogen of pancreatic juice to convert it to trypsin.

4. **Lipase** is an esterase, which hydrolyses fats (*i.e.* glycerol esters) into fatty acids and glycerol.

The internal surface of the *small intestine* is covered also with a multitude of minute projections called villi (Lat., shaggy hair) which give the surface a fine velvety appearance. These, however, will be described in our next lesson, as they are engaged in the *absorption* of all types of digested food.

When the partially digested food passes from the stomach through the pylorus, it almost immediately mingles with two very important digestive fluids, namely, the **bile** and the **pancreatic fluid**. The former is prepared by the liver, and the latter by the pancreas.

Both these fluids enter the duodenum at the same point (the duodenal papilla), one being conveyed from the liver by means of the **bile duct** and the other from the pancreas by the **pancreatic duct**. These unite near their point of entry into the gut.

THE PANCREAS, or sweetbread, is a large gland, partly situated within the curve of the duodenum, and weighing about seven ounces. In structure it closely resembles the salivary glands, but it is softer and more fragile. It secretes a fluid (pancreatic juice), and its islets yield **insulin**, which is directly absorbed into the blood.

The **pancreatic juice** is a colourless and transparent fluid, which is slightly alkaline and viscid, and of which half a litre is secreted daily. It contains 98 per cent. water, 1 per cent. organic salts and 1 per cent. organic bodies. The really important constituents are three enzymes :—Trypsin, amylase, lipase and sodium bicarbonate NaHCO_3 .

THE FUNCTIONS OF PANCREATIC JUICE.—These are very important in that it attacks and digests all three classes of foodstuffs.

1. **Trypsin** is present in the inactive form, trypsinogen. Apparently some constituent (enterokinase) of the intestinal juice (*succus entericus*) is required to convert it into trypsin which is active. Like pepsin, it is a proteinase and hydrolyses proteins into peptones, but works only in alkaline solutions.

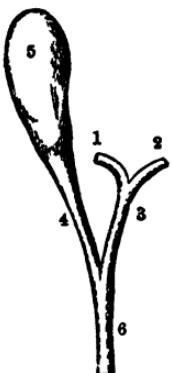


Fig. 94.—The Gall-bladder and its Vessels.

- 1, right hepatic vessel;
- 2, left hepatic vessel;
- 3, hepatic duct;
- 4, cystic duct;
- 5, gall-bladder;
- 6, common duct.

2. **Amylase** is a polysaccharidase—it converts starch and glycogen to maltose.

3. **Pancreatic lipase** is an esterase which splits glycerol esters into fatty acids and glycerol. If the pancreatic duct is ligatured a high percentage of undigested fat is found in the faeces.

Bile salts considerably increase the action of all the pancreatic enzymes. If both bile and pancreatic ducts are ligatured but little digestion of fat (10 per cent. or so) occurs, most of it is lost in the faeces.

MECHANISM OF PANCREATIC SECRETION.—

This is partly nervous (vagus) and partly chemical (secretin).

1. **Nervous Control.**—It has been shown that control of the pancreatic secretion is exerted by the vagus. There is a reflex secretion of juice very soon after the taking of food.

2. **Chemical or Hormonic Control.**—There must also be some other control, since cutting off all nerve supply to an isolated portion of gut still results in a pancreatic secretion. The duodenum secretes a substance called **secretin**, which gets into the blood stream, is conveyed to the pancreas, and there stimulates it to secrete.

THE FUNCTIONS OF INSULIN are entirely concerned with the fate of glucose. It enables the tissues to use glucose, the muscles and liver to store it as glycogen, and prevents the formation of sugar in the liver from protein. The precise mode of action of insulin is at present unknown.

THE BILE is the secretion of the liver. It may be collected from the gall-bladder, from a fistula, or in man, by swallowing a tube which enters the duodenum *via* the pylorus. Bile from the gall-bladder is thicker (due to mucus) and more concentrated than that from the bile duct. It is continuously secreted; gall-bladder bile has 10 per cent. solids, mostly bile salts.

Composition of Bile.—The bile contains bile salts, inorganic salts, mucus, cholesterol, and pigment derived from haemoglobin.

1. **Bile salts** (sodium glycocholate, and taurocholate) facilitate the action of pancreatic juice (especially the lipase), aid in the absorption of fat by lowering surface tension, and promote peristalsis.

2. **Bile pigments**—biliverdin and bilirubin are produced by the breakdown of haemoglobin. After being about a month in circulation the red corpuscles in some way become degenerate and are broken down in the spleen, marrow and lymph glands. The products of the decomposed haemoglobin are absorbed into the blood and the liver cells excrete them as the pigments

biliverdin and bilirubin. Some get into the faeces as **sterco-bilin**, and into the urine as **urobilin**, which accounts for the natural colours of these excreta.

3. **Cholesterol** and **lecithin** are found in bile. The former sometimes forms gallstones.

THE FUNCTIONS OF THE LIVER.

All the blood from the abdominal organs is ultimately collected up by the **portal vein** and conveyed to the liver, which deals extensively with the absorbed food.

1. It secretes bile continuously. This has been considered above.

2. A portion of the circulating amino acids is "deaminated" by the liver cells, *i.e.* ammonia is set free which combines with carbon dioxide and yields a waste substance called **urea**. This is turned out by the kidneys and excreted in the urine.

3. Absorbed fats are "desaturated" or reduced to forms which are more readily broken down into simpler fats, and ultimately to H_2O and CO_2 .

4. Galactose and fructose are converted to glucose, which latter may be stored as glycogen or changed to fat. Nucleo-

Fig. 95.—The Portal Vein and its Tributaries.

l., liver, under surface; *gb*, gall-bladder; *st*, stomach; *sp*, spleen; *p*, pancreas; *du*, duodenum; *ac*, ascending colon; *cd*, descending colon; *a, b, c, d, e*, the portal vein and its branches. Portions of the duodenum and colon have been removed.

proteins of the food are deaminated yielding uric acid as a waste product. This is absorbed into the blood and excreted in the urine by the kidneys.

5. Certain drugs and bacterial poisons (toxins) are rendered harmless—a process called "detoxication."

6. The liver produces **heparin** (which prevents blood from coagulating) and also **fibrinogen**.



7. The feeding with liver of a patient suffering from pernicious anaemia brings about a rapid improvement in his condition, leading eventually to a complete cure. How this is brought about is not known.

✓8. As a result of the many chemical processes going on, a considerable amount of heat is set free.

CHYME.—When the chyme passes into the small intestine it is soon mingled with the pancreatic fluid, the bile, and the secretions of the intestinal glands ; and these fluids, together with the saliva and the gastric fluid which form part of the chyme, complete the process of digestion. The intestinal juice (or succus entericus) is secreted from the whole length of the small intestine. It is an alkaline fluid and contains many enzymes, which act upon cane sugar, maltose and peptones, and render them fit for absorption. All kinds of foods are now being dissolved, and by the worm-like motions kept up by the muscular fibres of the intestines the whole is urged slowly on. The dissolved portions are rapidly absorbed by the mucous membrane, while the unabsorbed and indigestible portions pass onward towards the rectum.

CHYLE.—As soon as the chyme is subjected to the influence of the bile and pancreatic fluid, its appearance is changed, the emulsified fats giving it the appearance of milk. The term chyle is applied to the emulsified contents of the small intestine, and also to the contents of the lacteals and thoracic duct.

After the chyle has passed through the whole length of the small intestine it enters the large intestine through an opening which is guarded by two folds of the mucous membrane. These folds project into the large tube, and so prevents the reflux of the contents into the small intestine. Thus they form a valve between *ileum* and *cæcum*, known as the ileocæcal valve.

MOVEMENTS OF THE SMALL INTESTINE.—It is quite easy to study these by simply opening the abdomen of an animal which has recently been fed and then killed. It will soon be seen that there are two distinct types of movement. One is peristaltic, and it consists of waves of contraction passing progressively and slowly *down* the intestine. This is produced by the reciprocal action between the longitudinal and circular muscles in the gut wall. The effect of this is to slowly drive the contents onward. The other type of movement is known as rhythmic segmentation. A short length of gut suddenly breaks up into a number of small segments, the neighbouring halves joining together. Each new segment now undergoes a

similar division. This happens many times, and their effect is to produce thorough mixing and absorption.

MOVEMENTS OF THE LARGE INTESTINE.—

In the large intestine the main characteristics consists of a few sudden spasmodic contractions, known as "mass peristalsis," and occurring after the entry of food into the stomach.

No digestion occurs in the large intestine; the dissolved portions have been absorbed, leaving a residue which becomes more and more solid. The large intestine is mainly an excretory organ—only water is absorbed.

Putrefaction goes on extensively in the large intestine, the chief organisms present being Bacillus coli communis, B. pyocyaneus, sporogenes and various staphylococci. The large intestine is excretory for inorganic salts, especially Ca, Fe, phosphates Mg, Bi, Hg. It has no villi, but a certain amount of absorption does occur through its columnar-celled mucous membrane. A large number of the cells present are mucous secreting. We know that a certain amount of absorption must occur because—

- (1) The contents of the ileum are very fluid, that of the cæcum and ascending colon are quite soft, while that of the rectum is solid.
- (2) In certain cases the nutrition of patients may be temporarily kept up by the injection of nutrient enemata into the colon (*via* the rectum), but the amount of absorption is almost negligible.

The time occupied by the food in passing through the intestines varies considerably. A barium meal takes four hours to reach the ileocæcal valve, six hours to get to the hepatic flexure, nine to the splenic flexure, and eighteen to reach the pelvic colon—in average cases as judged by the X-ray shadow.

The fæces are the excretions of the large gut. About half a pound is passed per day, of alkaline reaction due to putrefaction. They consist of about 70 per cent. water, the rest being solids, made up of mineral salts, cellulose, unabsorbed and undigested food, and countless millions of dead bacteria.

Defæcation is the act of emptying the rectum. The desire to do so is brought about by the pressure of the entering fæces. The act is a reflex one, controlled by a centre in the lumbar region of the spinal cord aided partly by muscular action of the diaphragm and the abdominal muscles.

Meconium is the first excreta of the new-born baby. It merely consists of bile and mucus and contains no products of

bacterial action. It is green-black in colour, due to bile pigments.

NERVOUS CONTROL OF THE GUT.—The gut has its own rhythmic activity, but like other rhythmic organs it is correlated with the general requirements of the body by a double set of nerves :—

- (a) Sympathetic—which inhibits the movements, relaxes the sphincters, and causes constriction of the blood-vessels.
- (b) Parasympathetic—which increases the movements.

SUMMARY

THE SMALL INTESTINE—for digestion and absorption.

Coats	Serous—mesenteric reflexion of peritoneum.
	Supports gut, conveys blood-vessels, nerves, lymphatics.
Muscular	external longitudinal layer
	Internal circular layer } for peristalsis.
Areolar	for distribution of vessels and nerves.
Mucous	glands, to secrete the digestive fluids.
Villi	for absorption of digested foods
Valvulae conniventes	to increase absorbing surface.
Bile	aids pancreatic juice, stimulates peristalsis.
Pancreatic juice	converts starch→maltose→glucose, proteins→peptones→amino acids. fats→fatty acid+glycerol.
Digestive fluids.	Islets of pancreas—produce insulin. Succus entericus—reduces all foods to absorptive condition, <i>i.e.</i> to amino acids, glucose, fatty acid, glycerol.

Movements—are of two types :—

- a. Peristalsis—a slow onward movement, towards anus.
- b. Segmentation—sudden rhythmic subdivisions.

THE FUNCTIONS OF THE LIVER are :—

1. **Bile secretion**—aids pancreatic juice, removes bile pigments.
2. **Metabolic regulation** of all three types of food substances :—
Fats are desaturated and then oxidised.
Amino acids deaminated to urea, nucleo proteins to uric acid.
Glucose is stored as glycogen.
Galactose and fructose converted to glucose.
3. Prepares fibrinogen and heparin (anti-coagulant).
4. Excretes toxins.
5. Liver-feeding cures pernicious anaemia.

THE LARGE INTESTINE. Coats as with the small intestine.

No villi and no digestive fluids, only mucus.

Movements known as “mass peristalsis.” Absorbs water only.

Excretes faeces—70 per cent. water—unabsorbed and undigested food, salts, digestive juices, bacteria and bile pigments.

Nutrient enemas and anaesthetics may be injected per rectum.

INSULIN—produced by islets of pancreas.

Controls carbohydrate (glucose) metabolism.

CHAPTER XXI

ABSORPTION—THE LYMPH VASCULAR SYSTEM

ABSORPTION is the process by which the nutritious matter derived from the food during the process of digestion enters the blood system.

Food is taken in order to repair the waste which is continually going on in the various tissues of the body, and also, during youth, to allow of the growth and development of the system as a whole. It is also needed for the production of body-heat.

In the alimentary canal the various food-substances are simply *digested*, that is, converted into a soluble form, and capable of passing through moist membranous structures. But now it is necessary that the materials so digested enter the blood system and the lymph system. They are then conveyed to the various tissues and added to their structures, while the blood at the same time removes from these tissues those materials which have performed their office, and which are termed the waste products. The passage of the nutritious substances from the digestive canal to the blood or lymph system constitutes the process called **absorption**.

ROUTES OF ABSORPTION.—There are two ways:—

i. *Via the intestinal capillaries, leading ultimately to the portal vein*, which carries the absorbed material to the liver, there to be further dealt with.

We have noticed that the process of digestion commences in the mouth, and is continued more or less throughout the alimentary canal. We have also learnt that the whole of the canal is lined with a soft mucous membrane which is richly supplied with blood-vessels, and that as soon as the digestion of a food-substance commences, the dissolved portions begin to penetrate the soft membrane and pass through the thin walls of the minute blood capillaries. Thus we become acquainted with one process by which nutritious matter enters the blood, viz. absorption by blood-vessels.

The **blood-vessels** absorb digested carbohydrates, *i.e.* dextrose, and digested proteins, *i.e.* amino-acids. It must be

remembered that this absorption is carried on almost exclusively by the minutest blood-vessels (the capillaries), the walls of which are exceedingly thin, in order to allow the process to go on to the fullest extent. These processes are those of diffusion and osmosis, explained in Chap. IX.

There are two factors concerned in absorption. One is the purely physical action of osmosis and the other that of the living columnar cells lining the gut wall, whereby they will take in nutritive material. This latter is an active or vital process as contrasted with the passive mechanical one of osmosis. It involves the semi-permeability of the cell walls.

2. *Via the lymphatic vessels (lacteals).* The other portion of the process of absorption referred to above is carried on by a system of vessels called the **lymphatic system**, and the function performed by the vessels of this system is of a very important character. This we must now consider.

THE LYMPH VASCULAR SYSTEM (Lat. *lympha*, clear water) consists of *lymphatic capillaries*, *lymphatic vessels*, *glands* and two large vessels called *lymphatic trunks*, the larger of which is situated at the back of the thorax and is called the *thoracic duct*. It is so called because its vessels usually contain a watery fluid known as **lymph**.

The **lymphatic capillaries** are very minute vessels (Lat. *capillus*, a hair) which originate in the organs and tissues of nearly every part of the body. Those which have their origin in the walls of the intestines differ from the others in that they contain, during digestion, a fluid resembling milk in appearance. They are consequently distinguished from the other lymphatic capillaries by the name **lacteals** (Lat. *lac*, milk). The cause of this milky appearance is due to the fact that the lacteals absorb large numbers of fat globules derived from the digested food in the small intestine. We now proceed to study the nature and uses of these lacteals.

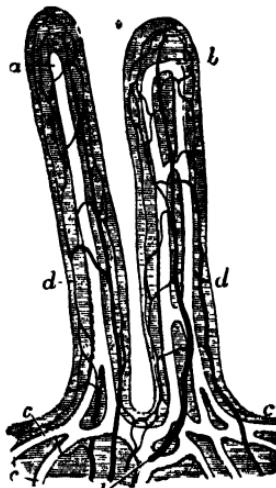


Fig. 96.—Two Intestinal Villi. ($\times 100$)

a, b, and c, lacteals; d, blood vessels.

It will be remembered that the small intestine is lined internally by a mucous membrane which is characterised by a number of minute hair-like projections called **villi**, giving the membrane the appearance of a yellowish or pinkish velvet. Each villus is supplied with a network of blood capillaries, and also one or more lacteals. These vessels are very advantageously situated for absorption, as they are surrounded on all sides by digested food-substances, only an extremely thin layer of tissue separating, viz. the columnar cells which line the outside of the villi. These cells seem particularly adapted for the process of absorption. Hence in the villi absorption goes on very rapidly, both by the blood-vessels and the lacteals. This is also supplemented by means of other blood-vessels and lacteals which lie in the mucous membrane *between* the villi.

The absorption as carried on by the lacteals differs in one important respect from that by the blood-vessels, since the former have the power to select the fatty constituents from the various products of digestion, while the latter absorb dextrose and amino acids.

Exactly how this is carried out is not known. All we can say is that it is necessary for the fat to be split up into glycerol and fatty acid before it can be dealt with by the villi. During their passage through the walls of the villi they are reconverted into fat, for as such it is found in the central lacteals.

During fasting the lacteals contain a clear, transparent fluid, closely resembling that which fills the other lymphatic capillaries; but during digestion they contain a milky fluid called **chyle** (Gr. *chulos*, juice), the change in appearance being due

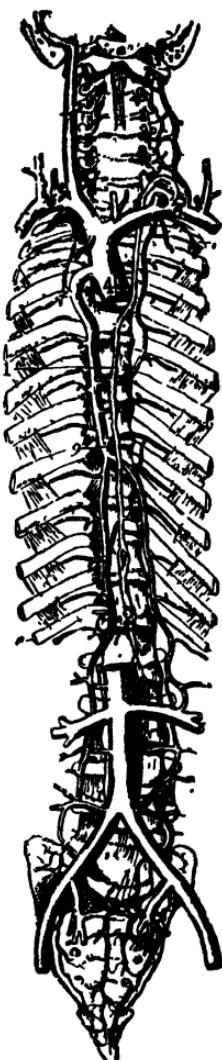


Fig. 97.—The Thoracic Duct.

1, the thoracic duct, in front of the vertebral column; its upper extremity communicating with the venous system at the junction of the left jugular and left subclavian veins (5 and 6); 2, receptaculum chyl.; 3, inferior vena cava, lower portion; 4, superior vena cava.

to the innumerable globules of fatty matter absorbed from the intestine.

The chyle is collected by **lymphatic vessels**, which resemble thin-walled veins. Like the latter they are also provided with **valves** which allow of the passage of fluid in one direction only, viz. towards the *thoracic duct*; and the valves are arranged at such short distances from each other that, when full, the lymph-vessels have a knotted or beaded appearance.

The lymph of the thoracic duct is viscid, opalescent and alkaline, with sp. gr. 1015. Lymph obtained from the duct is really a mixture of lymph from the limbs of the body, the liver and from the lacteals. It contains the same constituents as blood plasma, though the proportions are different, for it has more salts, but less proteins. It also clots.

As the chyle moves onward, and especially as it passes through the **lymph nodes**, more commonly known as **lymphatic glands**, the number of oily particles diminishes, and corpuscles resembling the white corpuscles of the blood (see page 158) appear. These are known as *lymphocytes*. They have been derived from the lymphatic glands: in fact, as it approaches the blood system, which it is ultimately to enter, it becomes more and more like blood, excepting in the matter of red corpuscles which give the colour. We may therefore regard the lymphatic glands as being concerned in the preparation of the white blood-cells.

Lymph Formation.—The **lymphatic capillaries** in other parts of the body have a blind origin in the spaces between the various structures. Their office is to collect the fluid part of the blood, *i.e.* the plasma, which exudes through the walls of the blood-vessels, and substances which, though having once formed part of a tissue, are not yet waste materials, but are capable of reorganisation, and may therefore be adapted for nutrition. This fluid is called lymph. The physical forces of diffusion and osmosis are undoubtedly used, but it is also probable that the permeability of the capillary walls can vary, for they are living, and do not act in the same way as a dead membrane.

The lymph thus absorbed by the **lymphatic capillaries** is collected by the **lymphatic vessels**, and transmitted through **lymphatic glands**. Lymph flow is unidirectional, always towards the lymphatic ducts. This is brought about by several means—the provision of valves, muscular contraction, respiratory movements help, and perhaps also the lymphatic veins themselves have some degree of contractility—for their walls have

a thin muscular coat. Some animals have lymph hearts which help in the circulation of lymph. The frog has two axillary and two sacral hearts. They also occur in the eel.

All the **lymphatic vessels**, including those which convey the chyle from the intestines, finally empty their contents into one of the two **lymphatic ducts**. The smaller of these, called the **right lymphatic duct**, enters a large vein at the right side of the root of the neck. The larger duct—the **thoracic duct**—lies just in front of the vertebral column. Its lower end, situated in the upper portion of the abdomen, in front of the body of the second lumbar vertebra, is four or five times as wide as the upper part, and is called the **receptaculum chyli** or **receptacle of the chyle**. The remainder of the duct lies at the back of the thorax, and its upper end opens into the angle of junction of the left subclavian vein with the left internal jugular vein. Thus, we have been able to trace the passage of food materials from the mouth, until they finally enter the blood-stream.

SUMMARY

ABSORPTION OF DIGESTED FOOD—by two routes:—

1. **By blood-vessels**—in mucous membrane of gut—all foods.
2. **By lymphatic vessels**—in all tissues, especially villi—fat only.

THE LYMPHATIC SYSTEM—the drainage and protective system.

1. **Capillaries**—blind origins, beset with valves for onward propulsion.
Lacteals, for fat absorption, only in the villi.
2. **Veins**—for gradual collection of lymph.
3. **Glands**—nodular collections of lymphoid tissue.
Lymph compelled to pass through them.
Produces lymphocytes, and is phagocytic.
4. **Ducts**—two, towards which the lymphatic veins converge.
 - a. Right—much smaller than the left.
 - b. Left—the **thoracic duct**—the main vessel.
Each enters blood-stream at junction of the internal jugular vein and subclavian vein, on its own side.
5. **Lymph**—the collected exudation from tissues+fluid in the lacteals.
Composition—Lymphocytes, fat globules, plasma proteins.
Flow—effected by mechanical pressure+use of valves.
Pressure is due to movement—muscular, respiratory, contractile.
Function—drainage of tissue spaces. Transport of fat (from gut) and lymphocytes from lymph glands to blood-stream.

CHAPTER XXII

METABOLISM

METABOLISM (Gr. *metabole*, change) is the name given to include all those chemical processes which digested food undergoes after it has been absorbed.

It is of great interest and of medical importance in the investigation of disease to follow up these changes. Actually, a great number of the intermediate changes are not known, but what is most fortunate, is that we need only to know the *total* energy values from start (*ingesta*) to finish (*egesta*). To begin with, experiment and calculation agree in showing that the law of the conservation of energy applies in biochemistry just as it does in ordinary chemistry. Also a given weight, say, of carbohydrate when oxidised (to CO_2 and H_2O), will always give the same amount of energy. With this as a basis, it is possible to put the subject of metabolism (with its applications in medicine, *e.g.* the calculation of diets and energy values in diabetes mellitus) on a sure footing. We must now consider the various matters that arise.

METHODS OF STUDY.—We need to know exactly how much energy (as heat and measured in calories) one produces under a variety of experimental conditions. The physicist would tell us that the method is to put the individual whose energy output is required into a calorimeter under these various conditions, and measure the amount of heat evolved. This is called "direct calorimetry." It is a tedious method, with elaborate and expensive apparatus, so physiologists have looked around for some other method more easily managed.

Now we know that for the oxidation of the food eaten, oxygen is required and CO_2 , H_2O , and urea expelled. There should be, and is, a quantitative relation between these. Fortunately, one only need determine the total amount of oxygen used and the ratio of the CO_2 expelled to the O_2 used (known as the respiratory quotient, R.Q.). Tables have been constructed giving for different values of the non-protein R.Q. the calories evolved per litre of oxygen used. This is known as the indirect

method of calorimetry and is in constant use in hospitals. Roughly speaking, we may say that for every litre of oxygen used there are five calories of heat produced. The apparatus needed is a bag to collect the air expired in five to ten minutes, a meter to find the total volume of this gas and a means of analysing a sample of the expired air. The bag is known as a Douglas bag, and the analysing tubes as a Haldane air analysis apparatus. The rest is a matter of arithmetic. By such means as this the calories per hour or metabolic rate can be determined for a patient, or for an experimental subject under any set of conditions as may be required.

BASAL METABOLISM means the very least output of energy which a healthy human being can give out. To do this he must be at rest, lying down, doing no work of any sort, and (to eliminate digestion) he must have had no food for 10 to 12

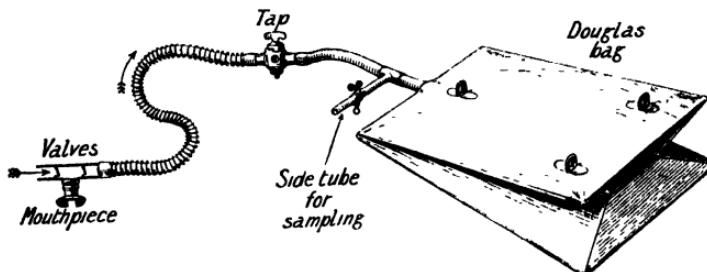


Fig. 98.—Apparatus for the Determination of Metabolic Rate.

hours previously. At this rate only his heart and respiratory muscles are at work, but he has also to maintain his body temperature. In these circumstances it has been found that a healthy man produces about 1,700 calories per day, which works out to forty calories per sq. metre of body surface per hour, or one calorie per kilogram body weight per hour.

In women the values are about 10 per cent. less.

ENERGY VALUE OF FOOD.—It is possible to carry out experiments in the laboratory with a view to finding out how much energy can be obtained from all sorts of food under different physiological conditions. As a result it has been determined that 1 gram of protein produces 4.1 calories of energy, 1 gram of fat 9.3 calories, and 1 gram of carbohydrate 4.1 calories. Knowing the composition of various kinds of food as regards its content in each of the three foodstuffs, we can therefore determine the energy value of these foods.

Various differences of opinion occur as to how the relative proportions of protein, fat and carbohydrates should be distributed. It seems, however, that 100 grams each of fat and protein with 500 grams of carbohydrate are probably somewhere near the mark. This gives us the following table :—

Food	Daily ration (gms.)	Cals./gm.	Energy (cals.)
Protein	100	4·1	410
Fat	100	9·3	930
Carbohydrate	500	4·1	2,050
			3,390

This is quite satisfactory for the "average" man.

RELATION BETWEEN WORK DONE AND ENERGY USED.—We can determine the evolution of heat per day by a man at rest. Then make him do work and again measure the heat evolved. Also by so arranging the work he does in an experimental manner this work can be separately determined. He therefore works a stationary bicycle (known as an ergometer) whose back wheel works a dynamo. The heating effect of the current produced can be measured by running it through resistance coils in another calorimeter. In this we get two values, the total energy produced and the amount converted to work. The ratio

$\frac{\text{energy as work}}{\text{total energy produced}}$

is known as the "efficiency." It is about 38 per cent. for trained athletes, but much less than this in our ordinary work—perhaps 20 per cent., comparable with a first-rate steam engine.

CONTROL OF HEAT PRODUCTION AND LOSS.

—Heat is *produced* in our bodies in several ways :—

1. By the chemical actions going on in the skeletal muscles whether at rest or in exercise,—the main cause. The most important chemical action producing heat is oxidation.

2. By the normal activities of the glands and muscles of the alimentary system, especially the liver and kidney.

3. By hormonal means—e.g. adrenaline and thyroxine.

Heat is *lost* in various ways :—

1. By the skin—the chief means—as much as 80 per cent.

in all. This is due to loss of heat by conduction, convection and radiation from the cutaneous blood-vessels, and from the evaporation of sweat (25 per cent.). The latter can only act if the atmosphere is unsaturated, and the other three nodes provided body temperature is above that of its surroundings.

2. By the exhaled air—17 per cent., though this depends largely on climate.

3. By the excreta—a mere trifle, say 3 per cent.

TEMPERATURE CONTROL.—Body temperature is confined to rather narrow limits (36° to 37° C.). It follows that there must be some very efficient control exerted. This may be theoretically either over the heat production or heat loss. Actually, both methods are used together, though the control of heat loss is the more important. It is surprising how great extremes of temperature can be endured by man in common with warm-blooded animals. This is due, as just explained, to his great ability in adjusting heat production and loss. There is experimental evidence to show that there is a controlling centre somewhere in the hypothalamic region of the cerebrum.

Premature babies have not properly developed controlling centres, so that they must be kept in incubation.

SUMMARY

METABOLISM—all those changes which absorbed food undergoes.
HOW DETERMINED—needed for the investigation of disease.

a. Directly—place patient in a specially constructed calorimeter.

b. Indirectly—determine total O_2 consumed in short time (10').

Every litre of oxygen means 5 calories of heat produced.

BASAL METABOLISM—minimum amount of energy expenditure.

Patient must be at rest, lying down, 12 hours after last meal.

Only cardiac and respiratory muscles working, and maintenance of body temperature.

$1,700 \text{ calories}/24 \text{ hours} = 40 \text{ calories}/\text{sq. metre body surface}/\text{hour}$.

ENERGY VALUE OF FOOD—Average food requirements:—

1 gram protein yields 4·1 calories	100 grams protein + 100 grams fat
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1 gram carbohydrate 4·1 calories	+ 500 grams carbohydrate
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1 gram of fat 9·3 calories.	= 3,400 calories.
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ENERGY REQUIREMENTS—basal metabolism+external work; manual workers, 3,000 calories; severe work, 4,000 calories.

TEMPERATURE CONTROL—by balancing heat production and loss.

Heat production—increased food (fats), increased metabolism.

Heat loss—cutaneous dilation, increased sweat, radiation.

CHAPTER XXIII

THE BLOOD-VASCULAR SYSTEM—THE BLOOD

In the case of unicellular organisms (protozoa) food is obtained by ingestion, oxygen can diffuse in, and carbon dioxide diffuse out, since all parts of the animal are in contact with the external environment. Such, however, cannot be the case with the metazoa, for the multiplication of the number of their cells makes the process of diffusion difficult and inadequate. Some more efficient means must be found whereby the organism can get its supplies of food, and excrete its waste matter. Oxygen must get to every cell, waste matter from every cell must find a way out, and, lastly, the digested and absorbed food must be able to get to all parts of the organism. To effect this nature has evolved various systems of transportation in the different creatures. In the case of vertebrates there is an elaborate series of pipes containing a specialised fluid known as *blood*.

THE BLOOD-VASCULAR SYSTEM is a closed circulatory one, of variable capacity, consisting of :—

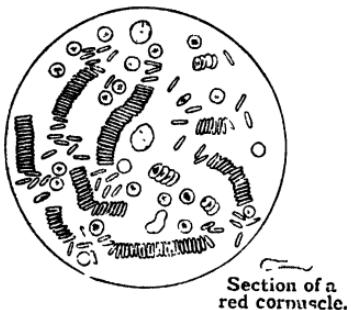
1. **A fluid circulating medium**, the blood, of special composition. It holds in solution the absorbed nutriment, transports it and oxygen to every cell of the body, and carries away waste material.
2. **A series of closed conducting tubes** (blood-vessels and lymphatics) which penetrate to all parts of the body, so that the above requirements may be adequately carried out.
3. **A propulsive mechanism** (a muscular pump—the heart) by means of which a continuous circulation is kept up.
4. **A regulating mechanism** (nervous and hormonic) which controls the system as a whole, and also correlates its behaviour with the rest of the body.

We begin with a detailed study of the blood.

THE FLUID MEDIUM—THE BLOOD—consists of a pale yellow alkaline colloidal fluid, the *plasma*, suspended in which are myriads of minute bodies, the *corpuscles* and *platelets*. The total combination forms an opaque scarlet fluid if the blood is oxygenated, but purple if deoxygenated. We must study each of the constituents in order.

1. THE PLASMA forms 55 per cent. of the total blood volume. It is a yellowish liquid containing many substances in solution—glucose, amino acids, inorganic salts, urea, serum albumin, serum globulin and fibrinogen. All the salts are ionised. The amounts of uric acid (2 mgs.), cholesterol (200 mgs.), urea (30 mgs.), glucose (100 mgs.) and Ca (10 mgs.) per 100 c.c. blood, are commonly investigated in the case of hospital patients. Marked variations from these amounts are of diagnostic value. Fibrinogen is important, as from it is produced fibrin when blood is shed. The calcium content is also important. It is controlled by the parathyroid glands (see the chapter on Endocrine Organs).

2. THE BLOOD CORPUSCLES are of two kinds, usually termed the *red* and the *white*, or the *erythrocytes* and the *leucocytes* respectively.



Section of a red corpuscle.

Fig. 99.—Blood as seen under the microscope, showing red corpuscles singly and in rouleaux. There are three white corpuscles.

that they contain a pigment known as *oxyhaemoglobin*. It is estimated that most of the solid matter (37 per cent.) of a red corpuscle is oxyhaemoglobin, the rest forming the framework or *stroma*. They are the bodies which, when seen *en masse*, give to the blood its uniform red colour. These corpuscles are very elastic, so that they readily change their shape in passing through narrow apertures, and regain it immediately after. They have no nucleus in adult mammals, but in other vertebrates (birds, reptiles, amphibia and fish) they are nucleated.

(b) The white or colourless corpuscles (*leucocytes*) vary in size from 8μ to 20μ . They stand in great contrast to the red cells. There are many sorts, differing considerably in size,

and staining properties. Their power of motion is very decided. The different varieties are :—polymorphs (50 to 65 per cent.), eosinophiles (1 to 3 per cent.), monocytes (4 per cent.), basophiles (0 to 1 per cent.), large lymphocytes (5 to 10 per cent.) and small lymphocytes (20 to 25 per cent.). The lymphocytes are formed in lymphoid tissue, the rest in red marrow. They much resemble a minute animal organism, found abundantly in stagnant water, called the *ameeba*. They also, like the amoeba, are constantly shooting out irregular processes, called *pseudopodia* (Gr. *pseudes*, false ; *pous*, a foot), and are therefore said to be capable of *amæboid movements*. The polymorphs attack and digest bacteria and damaged tissue. The colourless corpuscles are not nearly so numerous as the red, the

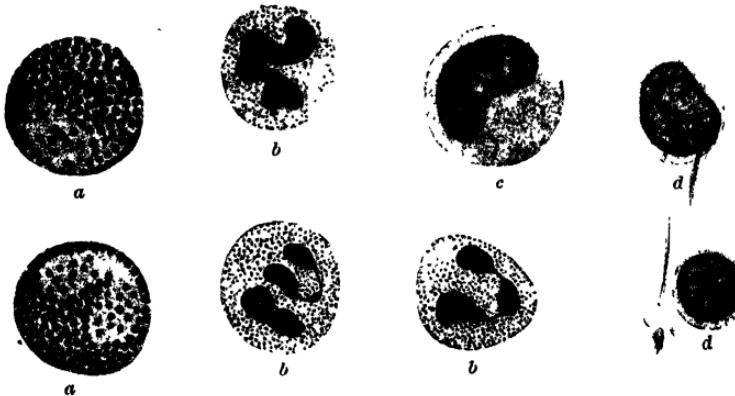


Fig. 100.—Varieties of White Corpuscles found in the Blood.

a, Eosinophiles ; *b*, polymorphonuclear leucocytes ; *c*, hyaline cell ;
d, lymphocytes.

proportion being about one to five hundred. Histologists distinguish many different sorts of white cells, probably varying in function and certainly in shape and staining characters. Leucocytes can move about, and take in (ingest) foreign particles, and dissolve them by an enzyme. It is an important property, since it is by this that invading bacteria are devoured and dead tissue removed. The clearing up of an inflammation is essentially due to this process of *phagocytosis*, as it is called.

(c) **Blood platelets** are small bodies about one-third the size of a red blood-corpuscle. They tend to stick together when blood is shed. Their origin is disputed. Some regard them as artifacts. Possibly they have something to do with coagulation.

Actually the blood is much more than the above. Thus it carries hormones from the glands in which they are made to those structures upon which they act. Similarly, the vitamins are carried from the gut, where they are absorbed, to all the body cells. Also the blood takes part in the defence of the body against injury and disease.

THE FORMATION OF A BLOOD CLOT.—When freshly-drawn blood is allowed to remain at rest for a few minutes it becomes semi-solid and jelly-like by the formation of what is called a **clot**. At first the clot thus formed constitutes the whole mass of the blood, and is of the same uniform colour. But after a short time a very pale yellowish liquid begins to ooze out and collect on the surface. The clot becomes gradually smaller as this liquid exudes, till, at the end of a few hours, it is much firmer, and floats in the yellowish fluid. About half is clot and the other half serum.

The clot is due to the formation of **fibrin**—a substance which is not present as such in living blood, but is formed spontaneously, after the blood has been drawn, from materials in solution. This change in the blood is termed **coagulation** (*Lat. coagulare*, to curdle); and the liquid which separates from the clot is called **serum**. The serum is almost entirely free from corpuscles, these being entangled with the fibrin.

The presence of corpuscles is not necessary for the formation of the clot, since this can occur in their absence.

The cause of the formation of fibrin is not properly understood. The following is an elementary account. Fibrin exists in plasma as **fibrinogen**. Shed blood is found to contain a substance called **thrombin** (*Gr. thrombos*, a lump), which can cause clotting. This thrombin is therefore present in circulating blood in some other form, called **prothrombin**, which does not cause clotting. However, when blood is shed in some way this prothrombin (in the presence of calcium and platelets) is converted to thrombin, which promptly converts fibrinogen to fibrin.

There are many difficulties which the above account has not gone into. We do not know why the blood in the circulation remains fluid. Other difficulties are the explanation of **haemophilia**, uncontrollable and persistent bleeding from a wound however trivial, and intravascular clotting (the occurrence of emboli or the production of thrombi after a surgical operation).

If fresh blood be stirred briskly with a bunch of twigs the fibrin is formed very rapidly, and collects on the twigs, leaving

behind a red fluid called **defibrinated blood** (blood deprived of its fibrin) which, of course, will not clot, because the fibrin which entangles the corpuscles is now absent.

Blood taken from a donor, and used for transfusion, is prevented from clotting by the addition of sodium citrate.

FACTORS WHICH AFFECT THE COAGULABILITY OF BLOOD.—The process of coagulation is retarded or prevented by a low temperature, by the addition of certain salts (usually sodium citrate), by the addition of leech extract (hirudin), by contact with oil, by an extract from dog's liver (heparin), by certain dyes, and with the living undamaged walls of the blood-vessels. The process of coagulation may be hastened, in drawn blood, by contact with foreign matter, addition of serum or clot, agitation, injury to vessel walls, and by keeping it at body temperature.

Under ordinary circumstances the coagulation sets in before the corpuscles have time to subside or settle to the bottom of the vessel; but the red corpuscles have a tendency to adhere to each other when the blood is at rest, forming rolls or columns resembling piles of coins, the piles being connected with each other at their ends so as to form a kind of network which sinks more quickly than would single corpuscles. When this change takes place rapidly the red corpuscles subside before the fibrin is formed. In this case a red clot is formed by fibrin and red corpuscles at the bottom of the vessel, over which is a yellowish clot produced by fibrin and colourless corpuscles.

HÆMOGLOBIN—THE RESPIRATORY BLOOD PIGMENT.—The colour of the blood is due to the presence of a pigment, called **hæmoglobin**, in the red corpuscles. This substance contains a very small proportion of iron, 0·4 per cent., and has the power of combining with oxygen gas. It is a compound of *haematin* and a protein known as *globin*. The *haematin* portion contains the iron. As the blood flows through the capillaries surrounding the air-cells of the lungs, the hæmoglobin combines with oxygen from the air, becoming of a bright scarlet colour. The blood thus changed in colour returns to the heart, by which it is forced throughout the body. Then, on passing through the tissues of various organs, and especially the muscles, the hæmoglobin gives up some of its oxygen, which seems to be held by only a feeble chemical affinity, to the carbon and hydrogen of these tissues, forming respectively carbonic acid gas and water. The hæmoglobin then changes to a dark purple colour, and the blood again returns to the lungs with the carbonic dioxide in solution. In the lungs this gas is given off into the air and expired, while the hæmoglobin receives a fresh supply of oxygen from the inspired air. From the above description it will be understood why hæmoglobin has been termed the *oxygen carrier* of the blood, and that the function of the red cells is purely respiratory.

The amount of hæmoglobin in the blood is of great importance. More can be made if needed—as in certain diseases, or in oxygen-want (high altitudes). 100 c.cs. of oxygenated blood will hold 18·5 c.cs. O₂ and contains about 14 gms. of hæmoglobin. In estimating hæmoglobin content we therefore use this as a standard of comparison. Many of the pigments found in the body are really derivatives of hæmoglobin, e.g. the bile pigments (bilirubin and biliverdin), the urinary pigment (urobilin), and faecal pigment (stercobilin). These contain no iron. Hæmoglobin is destroyed in the spleen and bone marrow, which reduce it to the state of biliverdin.

This latter is extracted out of the plasma by the liver cells, which excrete most of it as pigment (in bile and faeces).

In the body the bright scarlet blood is *usually* found in the **arteries** (vessels which convey blood *from* the heart), while the dark purple blood *usually* flows through the **veins** (vessels which convey blood *to* the heart). Hence the bright blood is often termed **arterial**, and the dark blood **venous**; but it is better to use the terms oxygenated and deoxygenated blood.

Thus the pulmonary veins (and the umbilical vein in the foetus) carry oxygenated blood, while the pulmonary artery contains deoxygenated blood.

THE TEMPERATURE OF THE BLOOD is about 98·4° F. or 36° C. in health, but is not exactly the same in all parts of the body at the same time. The temperature, moreover, is not exactly the same for all individuals. The high temperature is due to chemical action, chiefly the oxidation of carbon and hydrogen of the tissues. The blood is warmed as it passes through muscles, glands and other active organs, but is cooled slightly in the capillaries of the skin.

BLOOD COUNTS.—The number of corpuscles (per cu. mm.) is determined by an instrument known as a *haemacytometer* (Gr. *haima*, blood; *kutos*, cell; *metron*, measure). The principle of this instrument is that a known small volume of blood is diluted to a known degree and then transferred to a minute glass chamber placed under a microscope. The base of this glass box is accurately marked off into squares of known area. Its depth is also known, and thus its volume is determined. The corpuscles may then be counted when they have subsided. By various staining devices the enumeration of the red and white corpuscles can be separately carried out.

The normal average of red cells is about 5·5 million per c.mm. in the female, 6 million in the male; 6,000 to 8,000 white corpuscles, and a quarter of a million or more platelets per c.mm.

THE QUANTITY OF BLOOD IN THE BODY also varies. It is usually estimated at about one-eleventh the total weight of the body, but this is only to be considered as approximate. Of this amount it is estimated that one quarter is in the liver, a quarter in the skin and other tissues, another quarter in the heart, blood-vessels and lungs, and the remaining quarter in the skeletal muscles. In all there is about five to six litres.

Blood consists roughly of 78 per cent. water, the rest being solids. Of the solids by far the greater portion is organic.

Blood serum is a pale straw-coloured fluid, of alkaline reaction, and sp. gr. 1027. It consists of 90 per cent. water, the rest being solids of much the same nature as plasma, but of course there is no fibrinogen, as it has been used up in the formation of the fibrin. Of the solids 8 per cent. is protein. There are small amounts of oxygen and nitrogen dissolved in the plasma or serum, but, of course, the greater part of the oxygen is chemically combined with the haemoglobin of the red corpuscles. Blood can be caused to give up its oxygen, amounting to 18·3 and 12·1 c.cs. respectively, in 100 c.cs. of oxygenated and deoxygenated blood. Of this 0·3 c.cs. are physically dissolved in the plasma in the case of oxygenated blood, and 0·1 c.cs. in deoxygenated blood. Hence by far the greater portion must be chemically combined—90 per cent. and 60 per cent. respectively. Note that serum is plasma minus its fibrinogen (which has been converted into fibrin).

THE ORIGIN OF THE CORPUSCLES.—We have already seen that the red ones are produced in the red bone marrow, while the white corpuscles have their origin partly in red bone marrow (these are known as *leucocytes*), and partly in lymphoid tissue (these being known as *lymphocytes*).

USES OF THE BLOOD.—Some of the **uses of the blood** have already been pointed out in connection with certain organs, and others have yet to be mentioned. The chief uses, however, may be summarised as follows :—

1. Blood serves as a transitory storehouse for nutrient matter absorbed from the foods, and conveys the nutriment to all parts of the body.
2. It conveys the materials from which the secretions are formed to the various glands which prepare them.
3. In virtue of its haemoglobin it carries oxygen to all the tissues where the process of oxidation which is essential for the maintenance of the high temperature of the body goes on.
4. It collects up waste materials, *i.e.* products of katabolism, or break down, and conveys them to the excreting organs for separation and removal—especially CO_2 and urea.
5. It serves in a very efficient manner to distribute heat throughout the body.
6. It moistens the various tissues—*via* its exuded plasma.
7. It defends the body against harmful (pathogenic) organisms, or their products (toxins).
8. It conveys the various secretions of the ductless glands (autacoids) to the parts for which they were made.

BLOOD TRANSFUSION is now often carried out when a patient (the **recipient**) has lost a great deal of blood. It is made good by another (the **donor**) offering some of his as a substitute. The matter is not so simple as one might think—even apart from all technical difficulties. This is due to the fact that the serum of one person can cause the red cells of another to **agglutinate**, which means that the corpuscles tend to collect together in clumps, and then to haemolyse. One has therefore to find out first (by taking samples) whether such is or is not the case with recipient and would-be donor. It has been found that individuals can be divided into four groups when such tests are carried out.

SUMMARY

THE COMPOSITION OF THE FLUID MEDIUM—BLOOD

1. **Plasma**—is the fluid part (55 per cent. of blood volume).

Composition—proteins (albumin, globulin, fibrinogen).

Glucose, urea, inorganic salts, hormones, absorbed nutrient.

2. **Corpuscles**—the cellular part (45 per cent. of blood volume).

Reds—biconcave discs, 7.2μ diameter. 5.5 to 6 million/cu. mm.

Number increased in pregnancy, high altitudes.

Carry oxygen to the tissues *via* their haemoglobin content.

Developed from lining of marrow vessels. Life—4 weeks.

Whites—larger than the reds, amoeboid and phagocytic.

5,000 to 10,000/cu. mm., made up :—

Polymorphs (70 per cent.), lymphocytes (23 per cent.), eosinophils (3 per cent.), large mononuclears (4 per cent.).

Lymphocytes from lymph glands, leucocytes from red marrow.

3. **Platelets**—one-third size of red corpuscles, 250,000/cu. mm.

Concerned in blood coagulation. From giant marrow cells.

BLOOD—5 to 6 litres, about one-thirteenth weight of body.

Oxygenated—as oxyhaemoglobin (scarlet)—mostly in arteries.

Deoxygenated—as reduced haemoglobin (purple)—in veins.

Constituents—any marked deviation important in diagnosis.

Dextrose (0.1 gm. per cent.), calcium (10 mgm. per cent.), urea (30 to 40 mgm. per cent.), oxygen capacity (17 to 20 c.c. per cent.), haemoglobin content (14 per cent.).

Protective against infection—antibodies.

CLOTTING OF BLOOD—many theories held.

Prothrombin (in plasma)+damaged tissue juice and platelet action+calcium ions→thrombase.

Thrombase (an enzyme)+fibrinogen (in plasma)→fibrin.

BLOOD GROUPS—important in transfusions and paternity tests.

Difficulty is injected blood→agglutination→haemolysis→death.

Red cells of donor must be compatible with serum of recipient.

Blood of all human beings divisible into four groups.

Must determine to which groups donor and recipient belong.

CHAPTER XXIV

THE PROPULSIVE MECHANISM—THE HEART

THE HEART is a hollow muscular organ which, by its contraction, forces the blood through the whole system of blood-vessels. A general description of this organ has already,



Fig. 101.—The Sheep's Heart, anterior view.

1, right ventricle; 2, left ventricle; 3, right auricle; 4, left auricle; 5, the aorta; 6, a cut branch of the aorta; 7, pulmonary artery. To open the right ventricle, cut as shown by the thick unbroken line. To open the left ventricle, cut along the thick dotted line. Between these two lines is a groove containing a blood-vessel, marking the position of the septum which separates the ventricles.

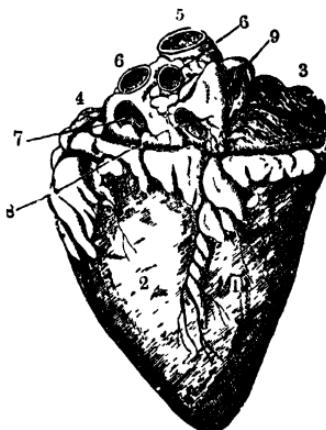


Fig. 102.—The Sheep's Heart, posterior view.

1, right ventricle; 2, left ventricle; 3, right auricle; 4, a small portion of the left auricle; 5, the aorta; 6, the pulmonary arteries; 7, pulmonary vein trunk, 8, vena cava inferior; 9, vena cava superior.

been given in Chap. XII., and we shall now proceed to study its structure and action.

The student is strongly recommended to procure a sheep's heart from the butcher, and dissect it with the help of the simple instructions here given.

Many of the sheep's hearts sold have a deep cut on the front. This is made on opening the carcase of the animal, while carelessly chopping through the breast-bone. Select one which is free from this defect, and one in which the blood-vessels at the base (upper and broader portion) are not closely cut. If a superabundance of fat surrounds the base of the heart, remove the greater portion of it without cutting any of the vessels.

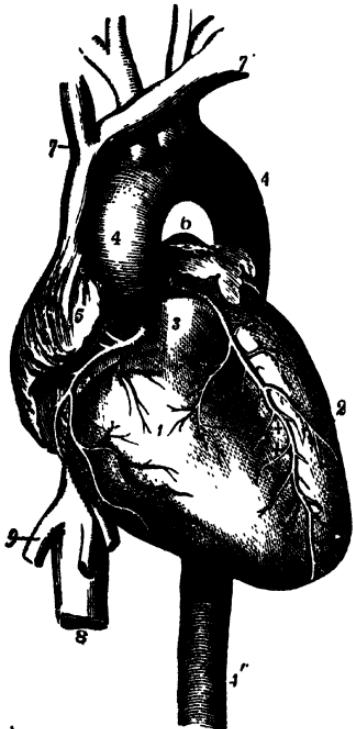


Fig. 103.—The Human Heart and its Vessels, anterior view.

1, right ventricle; 2, left ventricle; 3, 3', and 3'', the pulmonary arteries and their branches; 4' and 4'', the aorta; 5, right auricle; 6, left auricle; 7, veins which unite to form the vena cava superior; 8, inferior vena cava; 9, hepatic vein; +, coronary arteries.

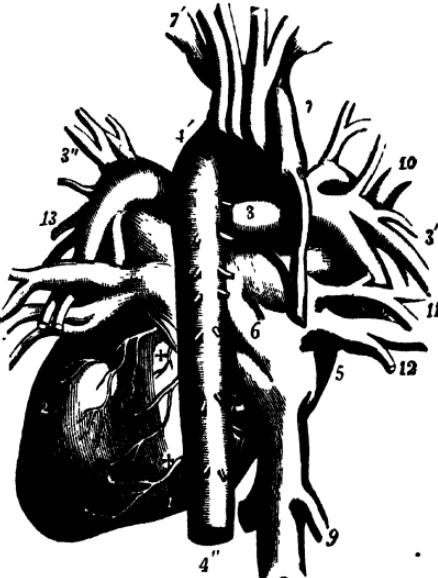


Fig. 104.—The Human Heart, posterior view.

1, right ventricle; 2, left ventricle; 3, 3', and 3'', the pulmonary arteries and their branches; 4' and 4'', the aorta; 5, right auricle; 6 is placed on the division between the right and left auricles; 7, superior vena cava; 8, inferior vena cava; 9, hepatic vein; 10, 11 and 12, right pulmonary veins; 13 and 14, left pulmonary veins; +, the coronary arteries.

The student, having provided himself with a sharp knife with a pointed blade, a few wood skewers, and a jug of water, may now proceed with the examination and dissection of the heart as follows:—

Place the point of the knife just underneath the surface of the heart, so as to raise a portion of the very thin membrane or skin which closely invests it. This membrane is the inner or serous layer of the pericardium, the outer or fibrous layer of which, it will be remembered, surrounds the heart loosely,

and is cut or torn away in removing the organ from the chest. A few remaining portions of this outer layer may still be seen attached to the great blood-vessels at the base of the heart, for it is here that the inner adherent layer is reflected back to form the outer and loose layer.

Now notice the two thin fleshy flaps which lie over the base of the heart like ears, one on each side. These are the **auricles** (Lat. *auricula*, a little ear). They are hollow, and, of course, when distended with blood, do not lie so flat. Notice also the general conical shape of the heart, with its broad base, for the entrance or exit of blood-vessels, and blunt apex.

We may now examine the **blood-vessels** at the base of the heart. If some of them appear to be small, portions may be cut down till we arrive at the point where the smaller vessels unite to form a large one. In this way we may readily reduce the number of blood-vessels to about seven. Some of these have very thick, firm, and elastic walls, which retain their circular form, although the vessels are quite empty. These are the **arteries** which

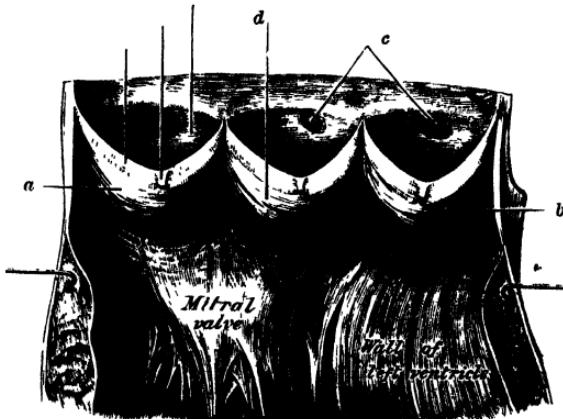


Fig. 105.—Aorta laid open to show the Semilunar Valves.

a, right posterior valve; *b*, anterior valve; *c*, origins of coronary arteries; *d*, left posterior valve.

convey the blood *from* the heart. The other vessels have thinner walls, which are comparatively inelastic and limp. These are the **veins**, which bring the blood *to* the heart.

It is now necessary to learn which is the right and which the left side of the heart. On the surface will be seen two grooves, on opposite sides, one situated in front, the anterior longitudinal sulcus, and the other behind, the posterior longitudinal sulcus. Inside the heart, extending between these grooves, is a fleshy partition which separates two cavities called the **ventricles** (Lat. *ventriculus*, a little belly)—the right and the left. These ventricles constitute the greater part of the heart, and are much stronger and more muscular (fleshy) than the auricles. We may now readily distinguish between the right and the left ventricles by pressing their walls between the finger and thumb, the walls of the left ventricle being about three times thicker than those of the right.

Now hold the heart before you in the position it would occupy (see fig. 101), supposing it to be the heart of a person facing you: that is, with its

base uppermost and its apex inclined to the left (your right), the left ventricle being on your right, and *vice versa*. From this stage it will be assumed that the student is able to distinguish between the four cavities of the heart, viz.—the right and left *auricles*, and the right and left *ventricles*.



Fig. 106.—The Human Heart. The Left Auricle and Ventricle opened, and part of the Wall removed to show the Interior.

1, pulmonary veins ; 1', the left auricle ; 2, a narrow portion of the wall of the auricle and ventricle preserved ; 3, 3', 3'', wall of the left ventricle ; 4, a small part of the wall of the ventricle preserved with a papillary muscle attached to it ; 5, papillary muscles ; 6 and 6', the segments of the mitral valve ; 7, the interior of the aorta, just above its semilunar valves ; 7', the arch of the aorta ; 8, the root of the pulmonary artery with its semilunar valves ; 8'', a separated portion of the pulmonary artery, remaining attached to the aorta by a cord ; 9, branches of the aorta ; 10, branches of the aorta.

By means of the wood skewers we may now learn the manner in which the various vessels communicate with these four cavities. The arteries will thus be seen to lead *direct* from one or other of the ventricles, while the veins communicate directly with the auricles, and indirectly through these with the

ventricles. Care must be taken to avoid tearing or breaking any of the internal structures while applying these tests.

THE GREAT BLOOD-VESSELS are those directly connected to the heart, namely:—

1. **The Aorta** is the largest *artery*, leading directly from the *left ventricle*. It is the main trunk which conveys oxygenated blood to all the tissues of the body.

2. **The Right and Left Pulmonary Arteries** are two other *arteries*, leading directly from the *right ventricle*. Nearer the base of the heart it will be found that these come from one vessel, the pulmonary artery. It is about 5 cms. long, and 3 cms. in diameter. It first passes in front of the aorta, then goes to the left of it, and lastly passes under the arch of the aorta where it divides into right and left branches of nearly equal size. They convey deoxygenated blood to the lungs.

3. **The Inferior and Superior Venæ Cavæ**.—Two large *veins*, communicating with the *right auricle*. The portions of these vessels nearest the heart are enclosed within the fibrous pericardium. They collect blood from all parts of the body and carry it to the right auricle. The superior vena cava collects the blood from the head and neck, while the inferior vein collects blood from the lower parts of the body. This blood is, of course, deoxygenated.

4. **The Pulmonary Veins** are four *veins*, communicating with the *left auricle*. Two proceed from each lung, and perforate the fibrous pericardium. They collect the blood which has circulated in the *lungs*, and convey it into the *left auricle*. But note, they contain oxygenated blood. It will be noticed that the auricle and ventricle of each side of the heart communicate with each other, so that the blood which has entered the auricle can pass into the corresponding ventricle.

THE INTERIOR OF THE HEART must now be examined. For this purpose proceed as follows:—

Hold the heart with its *front* surface toward you (see fig. 101), and make a clean cut through the wall of the *right ventricle*, about half an inch from the groove before mentioned, and extending from the top of the ventricle to the apex of the heart. Now open the ventricle by pushing aside this cut wall, and observe the following points in connection with its structure:—

The wall of the *right ventricle* is almost entirely *muscular*, and numerous columns of flesh (*columnæ carneæ*) project from its surface. Some of these stand out like pyramids, and are called the *papillary muscles* (Lat. *papilla*, a nipple). To these *papille* are attached very fine *tendinous threads* (*chordæ tendineæ*), which are again connected at their other

and upper ends with thin membranous flaps or *cusps*. The cusps are three in number, and lie loosely against the walls of the ventricle, but it will be readily understood that a pressure of blood in the ventricle would act on the under surfaces of these cusps and cause them to rise. Under these circumstances the tendinous cords are stretched, and the edges of the cusps meet so as to stop the communication between the ventricle and the auricle.

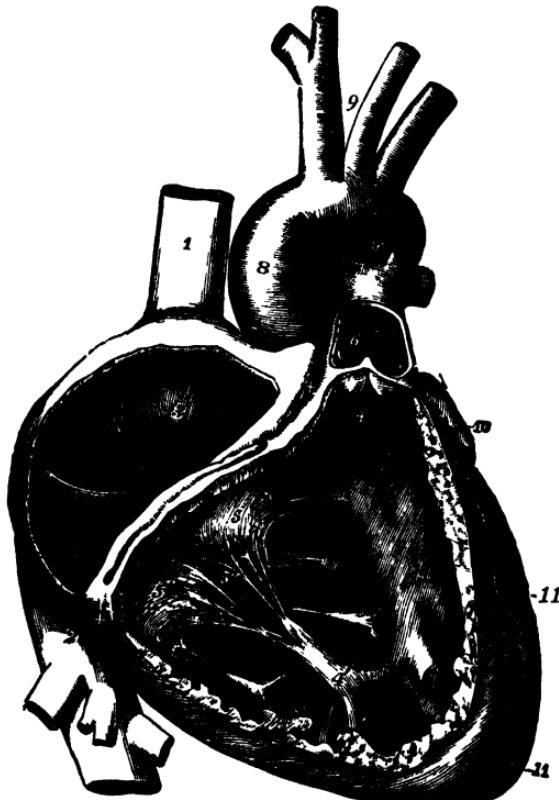


Fig. 107.—Interior of the Right Side of the Human Heart.

1, superior vena cava ; 2, inferior vena cava ; 3, interior of the right auricle ; 4, semilunar valves of the pulmonary artery ; 4', papillary muscle ; 5, 5', and 5'', cusps of the tricuspid valve ; 6, pulmonary artery ; 7, 8 and 9, the aorta and its branches ; 10, left auricle ; 11, left ventricle.

above it. The three cusps thus form a valve called the **tricuspid valve** ; and, from the arrangement we have just observed, it is clear that this valve will allow a free passage of blood *from auricle to ventricle*, but not in the opposite direction.

If we now prolong the cut towards the origin of the pulmonary arteries until we lay open the trunk which gives rise to these vessels, we shall find another set of valves called the **semilunar valves** (Lat. *semi*, half ; and

luna, the moon). These are three semicircular membranous pouches or cusps, with their convex surfaces turned toward the ventricle. They therefore offer no obstruction to the blood as it passes from the ventricle, but a backward tendency of the blood would fill the pouches, causing their edges to meet, and thus closing the passage into the ventricle.

Now remove the left auricle completely, with its four pulmonary veins, and notice the thinness and irregularity of its walls. We are now enabled to look down into the cavity of the left ventricle, which resembles the right in that a membranous valve lies between it and the auricle. This valve is called the **mitral valve** from its supposed resemblance to a bishop's mitre; it is also called the **bicuspid valve**, being composed of two cusps or flaps. They are furnished with *chordæ tendineæ* as on the right side, but they are thicker and stronger.

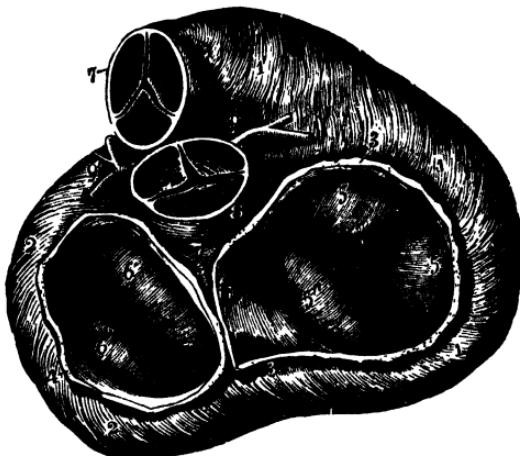


Fig. 108.—The Base of the Heart.

The auricles have been cut away, and the valves are closed. The pericardium has also been removed to expose the muscular fibres.

1 and 1, right ventricle ; 2, left ventricle ; 3, wall of right auricle ; 4, wall of left auricle ; 5, 5' and 5", the tricuspid valve ; 6 and 6', the mitral valve ; 7, pulmonary artery ; 8, aorta ; 9 and 9', coronary arteries.

As the left ventricle is as yet uncut, we may easily study the **action of the valve** as follows : Pour a little water into the ventricle, close the aorta which leads from it, and then squeeze the ventricle between the fingers and the thumb. Each time we do so we notice that the cusps of the valve float up on the surface of the water, till they partially or entirely close the ventricle.

If we remove the **right auricle** with its vessels (the *venæ cavæ*) we shall find that its structure is much like that of the left auricle. It is, however, a little larger than the left but its walls are a little thinner. It will hold about 60 cu. cms. It will also be found that there is another opening leading into it. This is known as the *coronary sinus*. It is the entrance for the venous blood returned from the substance of the heart. Again, by cutting through the walls of the **left ventricle**, we notice that this cavity closely resembles the ventricle already dissected, but that its walls are very much thicker. It

is, however, longer and more conical than the right. It also forms the *apex* of the heart.

Lastly, lay open the **aorta** as we did the pulmonary arteries, and here, at the origin of this great artery, we shall notice another set of **semilunar valves**, which are also arranged so as to prevent the blood from flowing back to the heart. If instead of laying open the aorta we cut it short immediately above the semilunars, we may fill the three little pouches with water, thus

illustrating their action, *i.e.* their tendency to close the passage from the aorta into the ventricle when acted on by a pressure from above. Just above the attached margins of two of the semilunars of the aorta may be seen two small openings, one in each hollow. These are the origins of the **coronary arteries**, by which the heart itself is supplied with blood for its nourishment. This blood is afterwards collected up by the **coronary veins**; and branches of both the coronary arteries and the coronary veins may be seen on the outer surface of the heart, the main vessels lying in the grooves outside the edges of the middle partition, and in the grooves



Fig. 109.—The Semilunar Valves of the Trunk of the Pulmonary Arteries, the Vessel being cut and laid open.

between the auricles and the ventricles. (See figs. 103 and 104.) The coronary veins finally unite to form the coronary sinus mentioned above.

THE SPECIAL TISSUES OF THE HEART are concerned with the initiation and propagation of the heart beat. Near the entrance of the superior vena cava is a mass of specialised tissue, which *initiates* the heart beat. It is therefore known as the **pacemaker** or **sino-auricular node** (S.A. node). Near the coronary sinus is another such mass of special tissue, called the **auriculo-ventricular node** (A.V. node). From this node a set of fibres, the A.V. bundle, arises, which splits into two, one running down each side of the ventricular septum. They branch repeatedly so that the fibres ultimately get to all parts of the ventricles.

The heart beat starts in the S.A. node, spreads all over the auricles (which contract simultaneously) to the A.V. node, then down both branches of the A.V. bundle and so to all parts of the ventricles, which also contract together.

The sympathetic and vagus nerves merely *control* the rate of heart beat, they do not initiate it. This is entirely the property of the nodal tissue just mentioned.

THE ELECTRO-CARDIOGRAPH.—The cardiac contractions, as with other types of muscle, are accompanied by electrical charges which can be investigated by an instrument,

the *electro-cardiograph*. It is not possible here to enter into any details with regard to this instrument, though the diagram shows a normal *electro-cardiogram*. This consists of two sets of waves or *complexes*, P being due to the auricle, and QRST



Fig. 110.—A normal electro-cardiogram. The rate is not rapid (66), the P-R interval is not increased, and the waves are physiological in type.

to the ventricle. By aid of it, the condition of the heart in patients suffering from various forms of heart disease can be determined, and diagnoses made. Also their improvement (or otherwise) under treatment can be noted from time to time.

SUMMARY

THE HEART—a pump to keep the blood circulating. Av. weight 10 ozs.
Four cavities—R. auricle→R. ventricle→lungs→L. auricle→L. ventricle.

Four valves—tricuspid, pulmonary, mitral, aortic—to ensure one-way traffic only.

R. auricle—thin walls, deoxygenated blood to R. ventricle.

Vessels { Vena cava superior—blood from head and neck.
Vena cava inferior—blood from rest of body.
The coronary sinus—blood from heart itself.

R. ventricle—thicker walls, papillary muscles, deoxygenated blood.

Tricuspid valve—with its chordæ tendineæ.

Vessels—pulmonary arteries (R. and L.), one to each lung.
Semilunar valves at commencement.

L. auricle—thin walls, oxygenated blood from lungs.

Vessels—pulmonary veins (R. and L.) from lungs.

L. ventricle—thick walls (three times R. ventricle); oxygenated blood.

Bicuspid (mitral) valve—with chordæ tendineæ.

Vessel—aorta with its semilunar valves.

Two coronary arteries (R. and L.)—to supply heart itself.

INITIATION AND CONDUCTION OF THE HEART BEAT.

S.A. node→auricular wall→A.V. node→A.V. bundle→
Purkinje fibres→ventricular wall.

ELECTRO-CARDIOGRAPH—an instrument to record the electrical changes accompanying each heart beat. Useful in diagnosis.

CHAPTER XXV

THE BLOOD-VESSELS AND THE CIRCULATION

We come now to the system of conducting tubes through which the blood circulates. It consists of *arteries*, *capillaries* and *veins*, which penetrate to all parts of the body.

THE ARTERIES, as we have already learnt, have *strong, tough and elastic walls*, and convey the blood from the heart.

These vessels have three distinct coats :—

1. The outer strong and tough layer of *areolar tissue*, containing some *elastic fibres* (*Tunica externa*).

2. The middle *muscular* and *elastic coat*. This layer is so thick in the large arteries that it forms the greater part of the wall. The muscular fibres are plain, and encircle the vessels (*Tunica media*).

3. The internal coat formed of *layers of elastic tissue*, lined with a delicate layer of *pavement epithelium* (better known as *endothelium*) (*Tunica interna*).

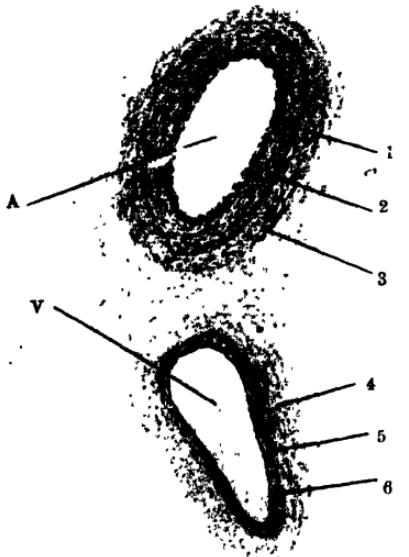


Fig. 111. — Transverse section through an Artery and Vein (human). ($\times 20$.)

A, artery; 1, 2, 3, its three coats.
v, vein; 4, 5, 6, the corresponding coats.

smaller arteries, till at last they give rise to the smallest vessels —the *capillaries*. It is to be noted that the arteries contain a great deal of muscular fibres. Now the function of muscle is to contract. Also this muscle is supplied with nerves as other

The large arteries divide into branches as they proceed from the heart, and these branches again divide and subdivide into smaller and

muscles are. Hence it will be seen that arteries can alter in size, not merely passively in virtue of their elasticity, but actively by nervous control of their muscular walls. These motor nerves for the involuntary muscles of arteries are known as vaso-motor nerves. They are regulated by a controlling centre (the vaso-motor centre) in the medulla oblongata. (See Chap. XXXI.)

It should be noted that arteries differ in the relative amounts of elastic and muscular fibres they contain. The larger ones situated nearer the heart are more elastic, while the smaller ones are much more muscular. It is these latter vessels which are controlled by the vaso-motor system.

THE CAPILLARIES (Lat. *capillus*, a hair) are very minute vessels, having an average diameter of 12μ , and length of 0.5 mm. They are generally arranged as a network, though the form of this network varies considerably in different parts. The walls of capillaries are exceedingly thin, being composed of endothelium only, i.e. they are but one layer deep, so that gases very readily diffuse through them, and, on this account, the changes which the blood undergoes during its circulation takes place chiefly in these vessels.

After the blood has passed through the meshes of the capillaries it is collected up by very small veins known as *venules*. These small veins unite, forming larger and larger veins, till at last they open into the great veins, the *venae cavae*, which take the blood directly into the auricles.

THE VEINS are very similar in structure to the arteries. Their walls are composed of the same three coats, but they are thinner, and the muscular and elastic fibres are not nearly so abundant. Hence the walls collapse when the veins are empty.

Many veins are also provided with **valves** like the semilunar valves of the heart, sometimes arranged at very short intervals, particularly in the veins of the limbs. All these valves are situated with their free edges turned toward the heart. Hence they allow the blood to flow freely towards that organ ; but any backward tendency on the part of the blood would fill these pouch-like valves, causing them to extend across and to close the vein. In small veins the valves are sometimes single, but generally they are arranged in pairs.

Arteries are as a rule deeply set, while many of the larger veins are situated very near the surface of the body, so near that their direction, as shown by the bluish tint visible through the skin, may be easily traced. This seems to be a protective action on the part of nature, as damage to an artery is much

more serious than that to a vein. If we lay bare the arm, we notice several of these veins on the front surface, and by pressing the finger along one of these in a direction opposite to the course of the blood we cause the blood to flow backward on the valves, thus filling them out, stopping the vein, causing it to swell out and present a knotted appearance.

If we thus prevent the blood from passing through one of the veins of the arm, we do not interfere with the general circulation, as the veins are connected with each other by numerous branches, and thus the blood can readily take another course; and, the total capacity of the veins being much greater than that of the



Fig. 112.—Capillary Blood-vessels in the Web of a Frog's Foot, as seen with the microscope.
a, small artery; b, capillaries; c, small vein. The arrows show the course of the blood.

a, small artery; b, capillaries; c, small vein. The arrows show the course of the blood.

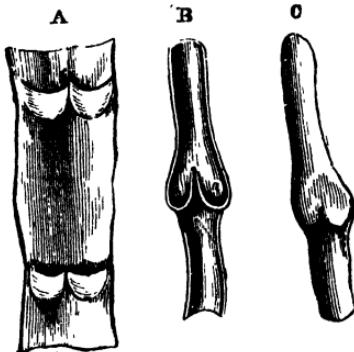


Fig. 113.—Diagram showing the Valves of Veins.

A, part of a vein laid open, with two pairs of valves.
B, longitudinal section of a vein, showing the valves closed.
C, portion of a distended vein, exhibiting a swelling at a pair of valves.

arteries, they are capable of conveying to the heart much more blood in a given time than they receive.

Some arteries come near the surface—the radial in the wrist, the carotids in the neck, the popliteal at the bend of the knee, and the femoral in the groin are familiar examples.

Some veins have no valves. Among these may be mentioned the *venae cavae*, the *pulmonary veins*, the veins within the cranium, the veins of the liver, the *umbilical vein*, the *portal vein* which supplies the liver, the *hepatic vein* (Gr. *hepar*, the liver) which takes blood from the liver, and the *renal veins* (Lat. *renes*, kidneys) which lead from the kidneys to the *vena cava inferior*. It is mainly the veins of the limbs that possess valves, especially the lower ones—to counteract gravity.

THE BLOOD VASCULAR CIRCULATION is naturally divided into two parts :—

1. The *systemic circulation* has to do with the left heart, for the aorta forces the blood around the body.
2. The *pulmonary circulation* has to do with the right heart, which pumps the blood through the lungs only.

THE EVENTS DURING A CARDIAC CYCLE.—

Having noticed the chief characters of the different blood-vessels, we now turn our attention to the **action of the heart**, commencing for convenience at that period immediately following the contraction of the ventricles, and during which the heart is passive. The cavities now dilate, and the blood flows freely

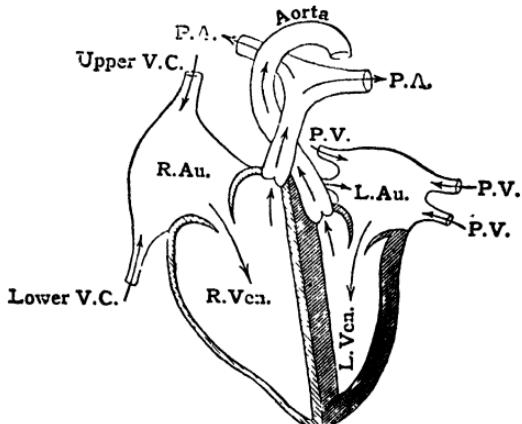


Fig. 114.—Diagrammatic section of the Heart to show the Chambers and direction of Blood Flow.

from the *venae cavae* and the *pulmonary veins* into the right and left auricles respectively, and thence into the ventricles. But as the auricles receive more than passes at once into the ventricles, their walls become fully distended. They then contract simultaneously, each one forcing its contents into the ventricle below it, the force of this contraction not being sufficient to send the blood back into the great veins, where it would be resisted by the pressure of the fluid they already contain. As the ventricles fill, the cusps of the tricuspid and mitral valves float up on the surface of the blood. Now follows the simultaneous contraction of the ventricles, the effect of which is to close the valves between them and the auricles, and also to open the semilunars at the entrances of the great arteries. The cusps of the tricuspid and

mitral valves are raised with such force that the chordæ tendineæ are tightly stretched, and the regurgitation of blood into the auricles is rendered impossible by the meeting of the edges of the cusps. The chief use of the tendinous cords is to prevent the valves from going too far into the auricles. It will thus be seen that when the ventricles contract there is but one course on each side open to the blood, namely, that furnished by the great arteries—the *pulmonary arteries* and the *aorta*, on the right and left respectively. These vessels are not only filled with blood, and that almost suddenly, but their walls are distended, since the blood is forced into them more rapidly than it can be received by their branches. The walls being elastic, they recoil on the blood, thus tending to force it both back into the heart, and also into the smaller arteries. But the backward pressure fills



Fig. 115.—Tracing of the Heart Beat of a Frog.

Upstroke = relaxation or diastole Down stroke = contraction or systole. Note the prehilarious auricular contraction, followed by that of the ventricle.

the pouches of the semilunar valves, with which the arteries on both sides are provided, thus preventing its motion in that direction; hence we see that the elastic recoil of the arteries assists the action of the heart in propelling the blood through the system.

The whole of the action just described occupies about eight-tenths of a second, and at every contraction of the ventricles about 60 c.cm. of blood are forced into each of the two arterial systems.

The cardiac output is estimated at about 4 to 6 litres/minute. During exercise this can be very greatly exceeded (up to 30 litres/minute) in the severest of exercise. It shows the enormous adaptive capability of the heart.

Fig. 115 shows a tracing taken of the beating of an excised frog's heart. Fig. 116 shows the arrangement of the apparatus used in order to keep the heart alive—by perfusion with saline.

We may feel the **beating of the heart** by applying the hand to the chest. This is said to be due to the tilting forward of the apex of the heart just at the commencement of the ventricular contraction, and its consequent beating the walls of the chest, between the fifth and sixth ribs, and about three and a half inches to the left of the mid line.

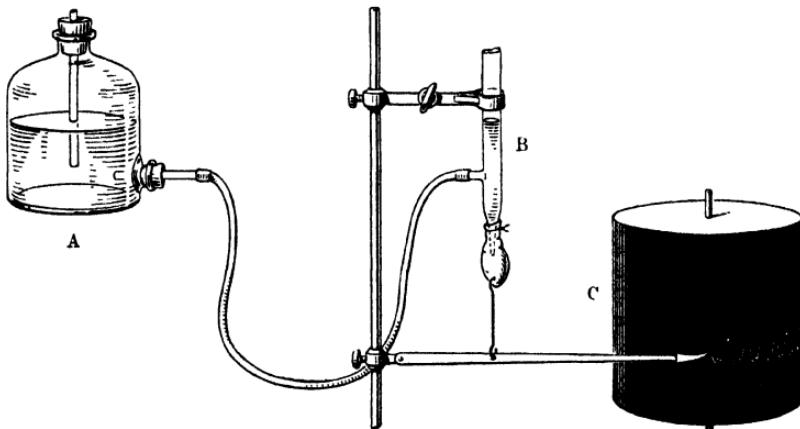


Fig. 116.—Apparatus for Perfusion of an Amphibian or Reptilian Heart.

A, contains the perfusion fluid, B, is the cannula tied into the sinus, with the apex of the heart tied to a lever, C, is the rotating drum covered with smoked paper.

The events of a cardiac cycle are as follows :—

1. General diastole or relaxation of whole heart— $0\cdot3''$. During this period the auricles and ventricles are filling. (Gr. *dia*, through; *stello*, I place.)
2. Auricular systole (contraction) about $0\cdot15''$, during which time ventricular diastole persists. Then follows :—
3. Ventricular systole, which lasts about $0\cdot35''$. Hence the whole ventricular diastole occupies $0\cdot45''$, while auricular diastole occupies $0\cdot65''$.

The **frequency of the beating** varies considerably with the age, activity, nervous excitement, posture, and various other circumstances. The average rates for persons of different ages are as follows :—

A new-born baby	140 per minute.
During the first year	120 "
" second year	110 "
" third year	95 "
" seventh year	87 "
" fourteenth year	85 to 80 "
In the adult :	80 to 70 "
In old age :	70 to 60 "

The heart beat is not quite regular—the variations being due to respiration. It is quicker in inspiration, due to lessened vagal activity, and slower in expiration owing to increased vagal activity. This is known as **sinus arrhythmia**, and is marked in children, but is of no clinical significance. Apart from this there can be quite marked differences in the pulse rate of different individuals, without their being in any way of pathological import.

Large animals have a slower rate than small, e.g. the elephant 30, lion 40, sheep 70, dog 100, cat 120, rabbit 150.

CARDIAC SOUNDS.—By applying the ear to the chest of another person we can hear the **sounds of the heart**. This method is known as **auscultation**. It is carried out more efficiently and with greater comfort with a **stethoscope** (Gr. *stethos*, the chest; *skopeo*, I see or examine).

- Auricular systole
- Ventricular systole
- General diastole
- Blood flow (A. to V.)
- A. V. valves closed
- Semilunar valves opened
- Impulse felt
- Cardiac sounds
- Electro-cardiogram

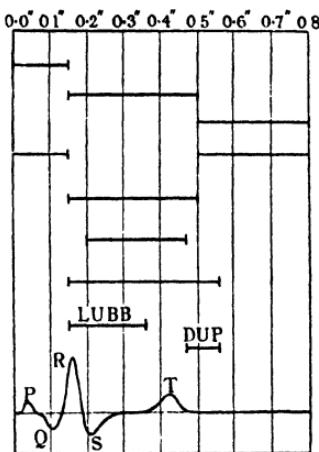


Fig. 117.—Diagrammatic representation of the events in a Cardiac Cycle (75/min.).

For every beat there are two distinct sounds, followed by a pause. The first or systolic sound is dull (*lubb*), and is produced by the vibration of the tricuspid and mitral valves, and also by the contraction of the walls of the ventricles. The loudness of this sound is indicative of the condition of the heart muscle. The second or diastolic sound is short and sharp (*dup*), and is undoubtedly produced by the sudden closure of the semilunar valves, i.e. at the start of the diastole.

The first sound is best heard at the apex in the fifth left intercostal space, occurring during ventricular systole, and the second at the base slightly to the right of the sternum over the second right costal cartilage, occurring at the start of general diastole.

VALVULAR DISEASE OF THE HEART. Two types.

(a) **Incompetence**, i.e. a failure of the valves to close properly, owing to diseased valves, enlarged orifice, or muscular weakness.

(b) **Stenosis**, i.e. a contraction of the orifice.

Each type is associated with its own sounds (known as **murmurs**), time relations, and pathological causes.

THE CAUSE OF THE HEART BEAT, as has been stated before, resides in the muscle itself, *i.e.* it has an inherent rhythm of its own; it is therefore said to be **myogenic**. During life it is controlled by nerves, but these only serve to make it keep up with the needs of the body. The vagus inhibits or slows down the beats, while the sympathetic accelerates them. An embryo heart beats at a time when no nerves reach it, showing that its automaticity is not dependent on them.

THE PULSE in the arteries is due to the sudden distension of their walls immediately after each ventricular contraction. We have already noticed that the blood is forced into the aorta by a series of jerks, each corresponding with the contraction of the left ventricle. Thus a rush of blood is produced in this vessel by each contraction, and is transmitted by it into the smaller arteries. Hence, if we cut an artery, the blood always issues in jerks. But as the arterial walls are elastic, and are distended by the blood pressure, the recoil tends to diminish the suddenness of each jerk, and, consequently, to convert the intermittent into a continuous stream. Thus, if we cut a very small artery, we notice that the jerks are considerably reduced, and the flow is continuous.

As the blood passes from the larger into the smaller arteries, and then into the capillaries, it comes in contact with a gradually increasing amount of surface. This multiplication of surface greatly increases the resistance offered to the blood by friction, which also tends to equalise the current as well as to reduce its velocity. Not only is the surface increased, but also the total sectional area of the small arteries or capillaries of any part is much greater than that of the large artery or arteries supplying that part, so much so that the velocity of the blood in the capillaries is only $\frac{1}{100}$ that in the aorta. As the blood passes onward into the veins, the velocity again increases, owing to the decrease of area, but the circulation in these vessels is less rapid than in the corresponding arteries, the capacity of the former being two or three times that of the latter. These facts explain how it is that, while the flow of blood from a cut artery is intermittent and rapid, the stream from a vein of the same size is continuous and slower.

The time required for a portion of the blood to make a complete circulation, *i.e.* to pass through arteries, capillaries and veins, is a difficult matter to determine. It is usually said to be about fifteen seconds. Seeing that the blood passes so slowly through the capillaries this may appear incredible, but it must be remembered that each portion of the blood passes through only a very short distance of capillary tube, probably about half a mm.

The onward flow of blood through the veins is due to several forces:—

1. The force of the heart beat transmitted through the arteries and capillaries. It is known as **vis a tergo**.

2. Muscular contractions (skeletal) aided by the presence of valves by which means the blood is persuaded to pass onwards and prevented from flowing backwards.
3. The suction action of the heart, during the general diastole. Also the aspiratory action of the thorax during inspiration. This is *vis a fronte*. It tends to draw blood into the thorax, while expiration has the reverse effect.

BLOOD PRESSURE.—It is of scientific and clinical interest to measure the pressure with which the blood is urged onwards, in the arteries, capillaries and veins. Arterial blood pressure may be measured in several ways :—

1. In animals by making it balance a column of mercury, known as a manometer. To do this an artery is opened and a “cannula” inserted. The manometer is fitted with a float and pointer which makes a tracing on a moving smoked paper.

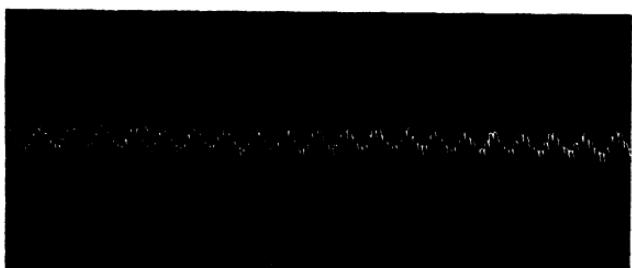


Fig. 118.—Blood-pressure Tracing—anæsthetised cat.

Note the rapid cardiac oscillations imposed upon the slow respiratory waves.

The cannula and attached tubing have to be filled with some anti-coagulant fluid (Na_2SO_4 , or MgSO_4). This gives us a record of the variations in the arterial pressure, which can therefore be investigated under a variety of experimental conditions.

On examining the tracing it will be seen that there are two sets of waves, a **slow**, which represents pressure variations due to respiration, and a **rapid** one giving the heart beats and their pressure variations—systole and diastole. It should be pointed out that the relative size (amplitude) of the waves is subject to great instrumental imperfections. Blood pressure rises during inspiration with quickening of the pulse and falls with expiration.

Tracings of venous blood pressure can likewise be taken, except that one uses a **water** manometer, since the pressures are so very much less.

2. In man we use a sphygmomanometer. Briefly this consists of a bag with a side tube, fitted around the arm. Air can be pumped into the bag *via* the tube and by connecting it to a manometer the pressure can be read. Pumping is continued until the pulse at the wrist ceases, giving the systolic pressure. The same apparatus can be used to measure diastolic pressure. The difference between these pressures is known as the pulse pressure, and has considerable diagnostic significance.

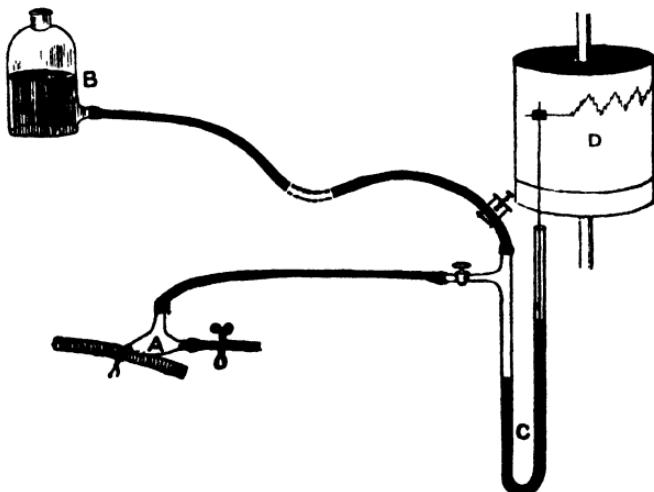


Fig. 119.—Apparatus for recording the Blood-pressure of an Animal.
A, cannula inserted into artery; B, bottle containing a saturated solution of Na_2SO_4 to prevent the blood clotting, and to provide a counter-pressure to that in the artery. It should be placed very much higher than here shown; C, the mercury manometer; D, rotating drum of smoked paper (kymograph) upon which the tracing of arterial B.P., as in Fig. 118, is recorded.

Capillary and venous pressures in man are estimated by finding the least pressure required to just blanch the skin. Some common average blood pressures in the adult are:—

Brachial artery	+ 120 mms. Hg.	relative to atmospheric pressure.
Capillaries	+ 30 mms. Hg.	
Small veins	+ 10 mms. Hg.	
Vena cava	- 5 mms. Hg.	

In the adult the normal **systolic** pressure in the brachial artery is somewhere between 110 to 140 mms., while the **diastolic** pressure is about 35 to 50 mms. lower. It is usual to record results as a fraction, *e.g.* 130/90, systolic pressure being put as the numerator and diastolic as denominator.

THE CONTROL OF THE VASCULAR SYSTEM.
—It is necessary that the efficiency of this system should be

maintained under all circumstances, otherwise death from asphyxia will result. It is clear from the general scheme of this system that control may be exercised either on the pumping arrangements (*i.e.* rate and extent of heart beat) or on the resistance to blood flow, since the blood-vessels are elastic and can alter their calibre.

Control of the heart output can be brought about either by alterations of rate (beats/minute) or amplitude of contraction. Generally speaking, both go together, increased rate with greater amplitude. These variations may be produced by :—

1. Direct action on the pacemaker (S.A. node), by a rise in blood temperature, as in fevers, or by increased auricular pressure, as in exercise.

2. *Via* the nerve supply, of which there are two :—

(a) The cardio-accelerator system (sympathetic), which is augmentor and increases the rate.

(b) The cardio-inhibitory system (vagus or parasympathetic) is the converse, for its stimulation slows the rhythm and depresses every part of the mechanism.

The former is set into action by exercise (causing rise of pressure in the right auricle), by anaemia, asphyxia or stimulation of any sensory nerve. The latter is always more or less in action. It is usually brought about by impulses arising in the aortic arch or carotid sinus, caused by variations in the blood pressure. Nerves pass from these places to the medulla, which then sends impulses down the vagal fibres to slow the heart.

Control of the blood-vessels is effected by two mechanisms.

(a) **The vasomotor nervous system**, which consists of two sets of nerve fibres, vaso-constrictors and vaso-dilators with corresponding centres in the medulla. These control the size of the lumen of all the arterioles. They, therefore, affect the peripheral resistance to blood flow, and hence the blood pressure.

(b) **Chemical control** is effected by certain hormones, such as adrenaline from the medulla of the suprarenal gland, vaso-pressin from the posterior pituitary gland, and acetyl choline, which is liberated at parasympathetic nerve ends. Adrenaline constricts the arterioles, histamine dilates the capillaries, while vaso-pressin constricts them. Many drugs are known, some of which will constrict (vaso-constrictors), while others will dilate the arterioles (vaso-dilators). Advantage is taken of this in clinical medicine.

Both control of heart rate, and of the calibre of the arterioles in all circumstances of normal health, enable the blood circulation to be effectively maintained.

FACTORS AFFECTING BLOOD PRESSURE.—It should be clear from what has been written that both the following factors can affect arterial blood pressure:—

1. **The cardiac output**, *i.e.* volume of blood ejected per ventricle per minute, 60 c.c./min. This depends on:—

- (a) The condition of the heart itself, *i.e.* its efficiency in respect of rate and force; and on
 - (b) The venous inflow of blood to the right auricle. The heart cannot pump out an adequate amount unless the supply is equal to the demand.
2. **The peripheral resistance.**—If the calibre of the arterioles is reduced the blood pressure rises (other factors remaining unaltered), and *vice versa*.

To a minor degree the volume of the blood could affect blood pressure—as in loss by haemorrhage, or increase by transfusion. Any effect, however, in this way would be but transient. Lastly, the condition of the arteries—loss of elasticity or obstruction of their lumen—would also affect the blood pressure, but this occurs only in disease.

THE CIRCULATION.—We may now view the circulation as a whole, tracing the course of the blood from a certain point till it arrives at that same point again. The blood which has been collected from all parts by the **venæ cavæ** is poured into the **right auricle**. It then passes into the **right ventricle**, and is forced through the **pulmonary arteries** into the lungs. After circulating through the **capillaries of the lungs**, where it gives up carbon dioxide and absorbs oxygen, it is collected by the **pulmonary veins**, and conveyed by them into the **left auricle**, and thence into the **left ventricle**. This ventricle contracts, forcing the blood through the **aorta** and its branches into **capillary networks in all the tissues**, excepting those few, such as the outer skin, the nails, hair, enamel of the teeth, etc., which are bloodless. It is then collected up by veins which convey it directly or indirectly into the **venæ cavæ**, thus completing the circulation.

It will thus be seen that there are two distinct circulations by which the blood can pass from one side of the heart to the other. One is called the **pulmonary circulation**, by which it passes from the right side to the left by means of the vessels of the lungs. The other is the **systemic circulation**, or the

circulation generally through the whole system, commencing at the left ventricle, and terminating at the right auricle.

The pulmonary circulation (Lat. *pulmo*, a lung) is not nearly

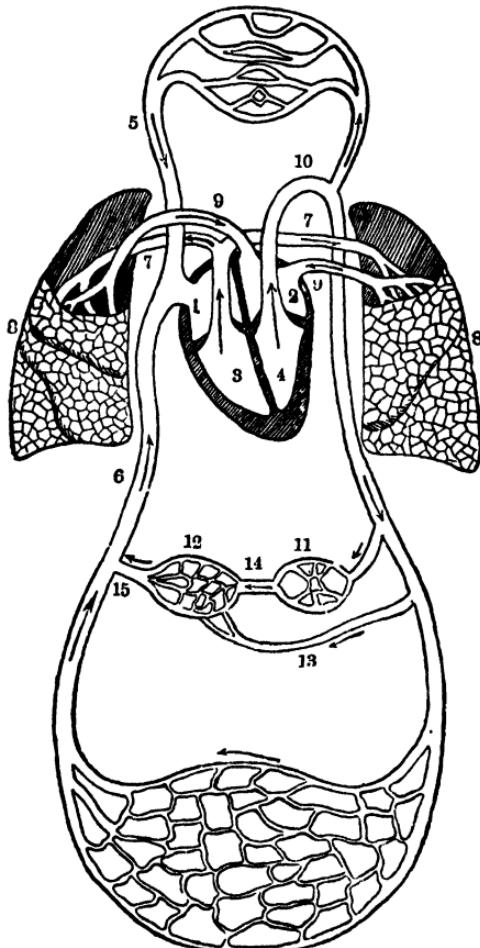


Fig. 120.—Diagram illustrating the Circulation.

1, right auricle; 2, left auricle; 3, right ventricle; 4, left ventricle; 5, vena cava superior; 6, vena cava inferior; 7, pulmonary arteries; 8, lungs; 9, pulmonary veins; 10, aorta; 11, alimentary canal; 12, liver; 13, hepatic artery; 14, portal vein; 15, hepatic vein.

so extensive as the systemic, and hence the peripheral resistance is much smaller. Less force is therefore needed to produce it, hence the reason why the walls of the right ventricle are so much

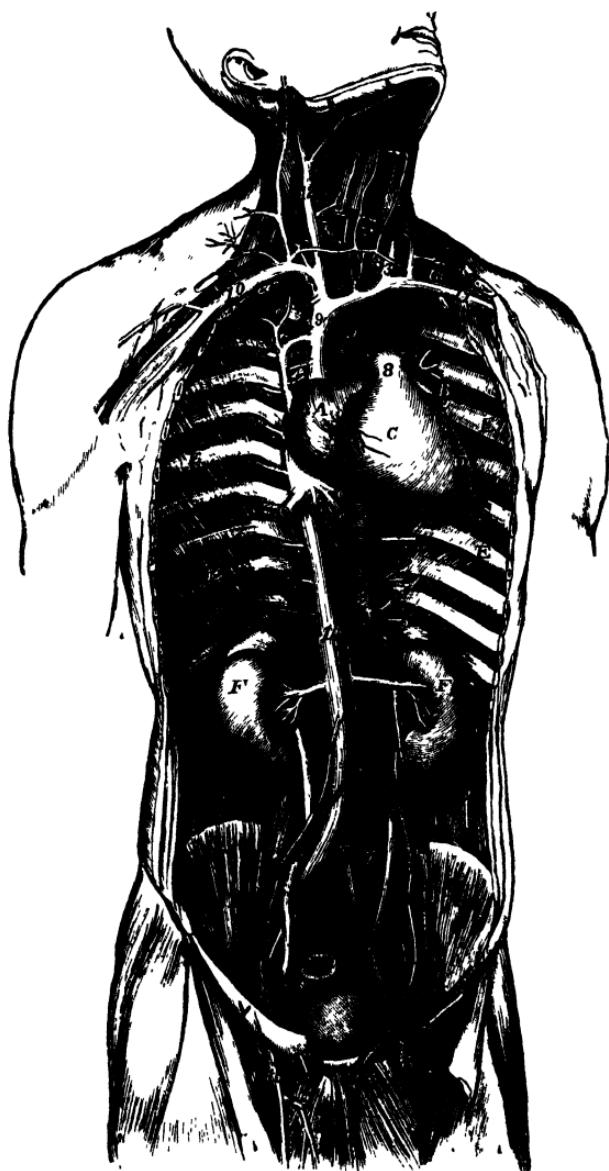


Fig. 121.—General view of the Heart and Great Blood-vessels of the Trunk.

A, right auricle; B, left auricle; C, right ventricle; D, left ventricle; E, ribs; F, kidneys; 1, arch of the aorta; 2, descending aorta; 3 and 4, right and left carotid arteries; 5 and 6, right and left subclavian arteries; 7, arteries supplying the lower extremities; 8, pulmonary artery; 9, vena cava superior; 10 and 11, right and left subclavian veins; 12 and 13, right and left jugular veins; 14, vena cava inferior; 15 and 16, veins which collect blood from the lower extremities.

thinner than those of the left. It is also to be noted that the pulmonary circulation is continually undergoing a rhythmic alteration, due to the alternate expansion and contraction of the lungs during respiration.

The **shortest course** which the blood can possibly take is the **coronary circulation** through the **coronary system**, or system of the heart. In this instance it enters the *coronary arteries* just outside the semilunars of the aorta, passes through a *capillary network*, and is then collected up by the branches of the *coronary veins*, which pour it direct into the right auricle by an opening lying between that of the inferior vena cava and that between the auricle and ventricle. Thus the blood completes a circulation without ever leaving the heart. Only birds and mammals have a coronary circulation.

The course of the blood in the body was first demonstrated by Harvey in the seventeenth century, 1628, and the following were among the **proofs** he gave as the results of his experiments :—

1. The heart propels in half an hour more blood than would make up the weight of the whole body.
2. The spurting of blood from the arteries corresponds in time intervals with the beats of the heart.
3. Clamp the great veins near the heart, and the latter becomes pale, flaccid and bloodless. On removal of the clamp, the flow is resumed.
4. Tie the great arteries, or the aorta itself, and the heart is distended and cannot empty itself.
5. All the valves are so arranged as to allow of a passage of blood in one direction only.
6. Poisons injected into a single blood-vessel soon produce an effect on the whole body.

To these may also be added :—

7. When an artery is cut, the bleeding may be stopped by pressing on the part *above* the wound, *i.e.* on the side nearer the heart.
8. When a vein is cut, we stop the bleeding by pressing on the portion *below* the wound, *i.e.* on the side remote from the heart.
9. The blood may actually be seen in motion, by the aid of a microscope, in the capillaries of the web of a frog's foot.

In Harvey's day it was not known how the blood got through the tissues from the arteries to the veins. This was determined by Malpighi in 1661, when, by the aid of the microscope, he discovered the capillaries.

THE SPLEEN is an organ difficult to classify, since it has

many and diverse functions. It is on the whole related to the blood and circulation. Its chief functions are :—

- (a) **Blood storage.**—As a reservoir for red cells, which can be forced into the circulation when its muscular fibres contract, as they do whenever there is oxygen-want (haemorrhage, CO-poisoning, high altitudes).
- (b) **Blood destruction.**—Some of its cells are phagocytic towards the erythrocytes. This leads to the appearance of bilirubin and iron.
- (c) **Blood production.**—The spleen produces lymphocytes and monocytes, while in the embryo it can also make red cells and leucocytes.
- (d) **Body defences.**—It plays a part in the defences of the body against infection, e.g. in malaria and typhoid fever. The spleen can be removed (splenectomy) with no ill effects. There is a general compensatory enlargement of the lymphatic glands throughout the body.

SUMMARY

BLOOD-VESSELS—a vascular system for blood circulation.

- 1. **Arteries**—carry blood from the heart; blood in them is pulsatile.
Larger arteries more elastic, smaller ones more muscular.
With few exceptions contain oxygenated blood.
- 2. **Capillaries**—connect arteries with veins. Thin walls (endothelium).
Very short (0.5 mm.), and very narrow (12 μ).
Ready diffusion of O₂ and CO₂ through walls.
- 3. **Veins**—convey blood to heart, sluggish flow. Deoxygenated blood, except in pulmonary and umbilical veins.
Some have valves to prevent back flow and counteract gravity.

THE HEART BEAT—contractions are myogenic in origin.

Apex beat—in fifth left intercostal space, 3·5 inches from mid line.
Rate—120 (young child) to 60 in old age.

Depends largely on circumstances—sex, age, exercise, disease.

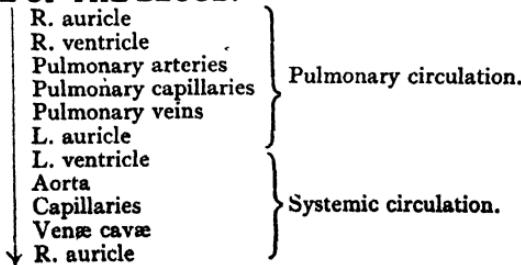
Cycle { Auricular systole 0·15", auricular diastole 0·65".

Ventricular systole 0·35", ventricular diastole 0·45".

Sounds—*Lubb*—dull sound, due to muscular contraction.

Dup—due to sudden closure of both semilunar valves.

COURSE OF THE BLOOD.



BLOOD PRESSURE—exerted on the vascular walls by the contained blood—systolic and diastolic. Children 100/60, adults 120/80.

Measured—in animals by a manometer connected to a cannula inserted into an artery (or vein).

in man by using an inflatable armlet connected to a pump and manometer.

CONTROL OF THE VASCULAR SYSTEM—as part of the co-ordination of the bodily needs.

1. **By the heart beat**—variations in the force pump.
 - a. By action on the pacemaker—changes in temperature or auricular pressure.
 - b. By the autonomic nervous system.
Parasympathetic (vagus)—decreases force, slows rhythm.
Sympathetic—augmentor, increases rate.
2. **By the blood-vessels**—variation in peripheral resistance.
 - a. By the vaso-motor system—nerves and medullary centres.
Vaso-dilators—lumen enlarged, B.P. falls.
Vaso-constrictors—lumen constricted, B.P. rises.
 - b. By chemical substances—autacoids, drugs.

THE SPLEEN has the following functions :—

- a. A reservoir for blood, especially the red cells.
- b. Some of its cells are phagocytic towards the red cells.
This leads to the production of bilirubin and iron.
- c. It makes lymphocytes and monocytes, while in the embryo it also produces leucocytes and red cells.
- d. It helps in the defence against infection.

CHAPTER XXVI

RESPIRATION

THE energy which all cells need for their continued existence is, with few exceptions, derived from the oxidation of absorbed material. The oxygen is obtained from the air in the case of land animals, and water in the case of aquatic animals. The former obtain their oxygen directly from the air, and the latter from that which is dissolved in the water. At the same time, and with the same apparatus, nature gets rid of the one and only waste product which is gaseous, namely, carbon dioxide.

Respiration in its wide sense means all those processes involved in the interchange of O_2 and CO_2 between the organism and its environment.

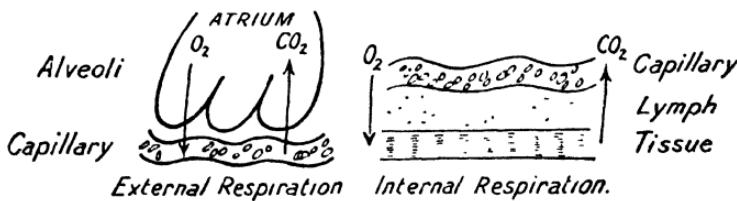


Fig. 122.—Scheme of Respiration—External and Internal.
The arrows show the direction of passage of oxygen in and CO_2 out of the tissues, and the pulmonary capillaries

This is effected in two stages. Thus the oxygen must get into the capillaries, and from them into the tissues, with similar remarks applying to the carbon dioxide. Thus respiration, in the ultimate but somewhat restricted sense, is this latter exchange between capillaries and tissues. It may therefore be termed an **internal respiration**. The taking of oxygen into the capillaries and the giving out of carbon dioxide from the capillaries to the lungs is the **external** aspect of respiration. We may therefore consider the two subjects of :—

i. **External respiration**—a mechanism to get oxygen in and carbon dioxide out of the blood capillaries. In this respect we find that frogs have both pulmonary and cutaneous respiration, fishes have branchial (gill) respiration, and all air-breathing vertebrates have pulmonary respiration.

2. Internal respiration—those processes involving interchange of oxygen and carbon dioxide, between blood capillaries and tissue, *via* the mediation of the tissue fluid which bathes capillaries and cells.

We have noticed that the blood becomes deoxygenated in the capillaries of the tissues of most parts, but, of course, not so in those of the lungs. This is due to the fact that some of its oxygen has united with carbon and hydrogen of the waste matters, forming carbon dioxide and water. The oxygen supply was obtained from the air in the air-cells of the lungs, and was conveyed to all parts by the blood-stream.

Life could not be maintained for even a short time without this oxidation, for not only is it the great source of heat by which the body temperature (36° C.) is maintained, but also provides the energy for all the cell activities. It is also a means by which waste organic matter is converted into simpler compounds (*carbon dioxide, water, and urea*) previous to removal. Note, that of the five classes of vertebrates (back-boned creatures), viz. fish, amphibians, reptiles, birds and mammals, it is only the two latter which are "warm blooded." That is, their bodies are maintained (within very narrow limits) at a constant high level independently of that of the surrounding air or water.

The lungs are a source of gain to the blood, for the inspired oxygen taken up by the red corpuscles is utilised in the tissues for oxidative purposes. All waste matter is readily taken up by the blood and transported to those organs destined to remove them.

When the deoxygenated blood laden with reduced haemoglobin reaches the capillaries which surround the air-cells of the lungs, it is immediately changed in colour, becoming bright scarlet, due to the formation of oxyhaemoglobin. Carbon dioxide passes through the thin layer of membrane which separates the blood from the air, and oxygen gas passes from the air into the blood. This process whereby gas passes across a membrane from one side, that of the blood or air, to that of the air or blood, is known as *diffusion*. We see, then, that the lungs do not *prepare* carbonic acid gas, but simply serve as a means by which this gas, brought by the blood from the tissues, is excreted.

COMPOSITION OF INSPIRED AND EXPIRED AIR.—The extent to which these changes take place in the body may be judged by comparing expired with inspired air.

The latter contains about 79 per cent. of nitrogen, 21 per cent. of oxygen, with only about 0·04 per cent. of carbon dioxide and a variable proportion of water vapour; while the expired air contains about 4 per cent. carbon dioxide, 16 per cent. oxygen, and an increased proportion of water vapour, the nitrogen remaining the same. Also the expired air is warmed, and slightly less in volume than inspired air, under the same conditions.

With regard to the analysis of expired air it should be noted that, strictly speaking, it is the composition of the air in the alveoli that is required. Hence ordinary expired air is a mixture of alveolar, bronchial and tracheal air. At the end of a deep expiration (after a normal inspiration) the expelled air is as nearly alveolar as it is possible to obtain it. A sample of this shows, on analysis, a remarkably constant composition. The percentage composition of inspired, expired and alveolar air is given in the following table:—

	Inspired air.	Expired air.	Alveolar air.
Oxygen . . .	20·96	16·4	14·0
Nitrogen . . .	79·00	79·5	80·5
Carbon dioxide . .	0·04	4·1	5·5
Temperature . .	Variable	34° C.	37° C.
Water vapour . .	Variable	Saturated	Saturated

ASPHYXIA.—It follows from this, that if a person were to shut himself up in a room without any means of ventilation whatever, the air he breathed would gradually lose its oxygen, and gain a corresponding proportion of carbonic acid gas. When 1 or 2 per cent. of the oxygen had thus been removed, a feeling of general uneasiness would arise, accompanied by headache; and as the loss increased, there would not be sufficient oxygen in the inspired air to change the colour of the blood. This would certainly be the case when the loss of oxygen and the gain of carbonic acid gas rose to 10 per cent. The blood would then be venous throughout the system. Carbonic acid gas, which is in itself slightly poisonous, would saturate the blood; and this, together with the oxygen starvation, would speedily cause death from suffocation or **asphyxia** (Gr. *a*, without; *sphuszo*, I throb—cessation of pulse).

It is usual to divide the phenomena of asphyxia into three stages: First, that of increasing rate and depth of breathing (*dyspnoea*), then the stage of expiratory convulsions, and lastly, that of exhaustion.

The physiological events in asphyxia are due to both the decrease in oxygen and the increase in carbon dioxide. The effect of oxygen-want is not noticed until the oxygen percentage falls to about 14.

When an animal is strangled, choked or drowned, the same condition (asphyxia) ensues. In these cases no oxygen can enter the blood, while the carbonic acid gas is fast accumulating by the oxidation of the tissues, and soon saturates the blood, all of which rapidly becomes venous. The occurrence of death in a few minutes shows the importance of oxygen gas in the renewal of the deoxygenated blood.

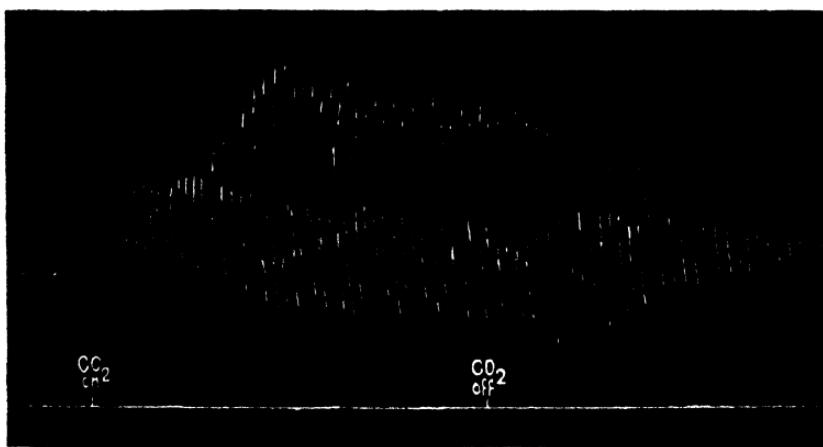


Fig. 123.—The effect of CO₂ on the Respiratory Movements in the Normal Animal.

The inspired air contained 3 per cent. CO₂ during the period marked on the tracing

EFFECTS OF VARIATION IN CO₂ AND O₂ CONTENT OF INSPIRED AIR.—It is important to know the effects produced by any departure from the normal percentage of these gases in the air breathed.

Variations in the oxygen percentage:—

100 per cent.—no harmful effect, if only temporary.

70 per cent. (or less) may be inhaled with impunity.

17 per cent. will just extinguish a candle.

14 per cent. causes slight hyperpnoea and cyanosis.

8 per cent. produces sudden loss of consciousness.

Death in coal mines is perhaps more often due to CO (after-damp or carbon monoxide) poisoning.

Variations in the CO₂ percentage :—

- 30 per cent. or more produces anaesthesia leading to death.
- 6 per cent. distressful breathing with severe headache.
- 5 per cent. produces marked hyperpnoea, even at rest.
- 3 per cent. is only noticeable on exertion.

Carbon dioxide is a valuable respiratory stimulant. A mixture of 93 per cent. O₂ + 7 per cent. CO₂ compressed into steel cylinders is commonly employed for the restoration of people who have been suffocated, as in coal-gas poisoning or drowning.

We have now learnt the necessity of ventilating our rooms—that is, of allowing for the removal of the expired air, and for the access of pure air from the outside atmosphere to take its place. Another important point is that the air should be kept moving, but at the same time the movement should be so regulated as to avoid the production of draughts.

RESPIRATION RATE.—This is dependent on age, sex, exercise, disease and other circumstances. Thus we have the following rates per minute: Baby 40, child 26, adult 16. The ratio heart rate/resp. rate is about 4·5 to 1, and is fairly constant in normal health. In disease the ratio may vary either way, and is of some diagnostic value.

QUANTITIES OF AIR BREATHED.—Although we are continually expiring and inspiring air, yet the lungs are never empty—in fact, the amount of air which enters and leaves the lungs during ordinary breathing, viz. 500 c.c., is small compared with that which remains after each expiration (2,500 c.c.).

This air which passes in and out of the lungs in ordinary quiet breathing is called the **tidal air**, by analogy with the ebb and flow of the tide. After each *expiration*, however, about 2,500 c.c. still remain in the lungs, this being termed the **stationary air**. By making a very deep expiration we can expel about a half of this (the **supplemental air**), and the lungs then contain about 1,000 c.c. of **residual air** which cannot be expelled.

From the above statements we learn that the lungs contain about 3,000 c.c. after an ordinary *inspiration*; that is, the 2,500 c.c. of stationary air, together with the 500 c.c. of tidal air. By taking a very deep inspiration we can add about 1,500 c.c. to this, bringing the total up to 4,500 c.c., thus inflating the lungs to their full capacity. The term **complementary air** has been applied to the 1,500 c.c. added by the deep inspiratory effort.

In *deep breathing*, as during exercise, the tidal air is of course considerably increased, and includes the complementary air plus some of the supplemental air (see diagram).

VITAL CAPACITY is the amount of air which can be expelled by a forcible expiration after the deepest possible inspiration. It is therefore the sum of the complementary tidal

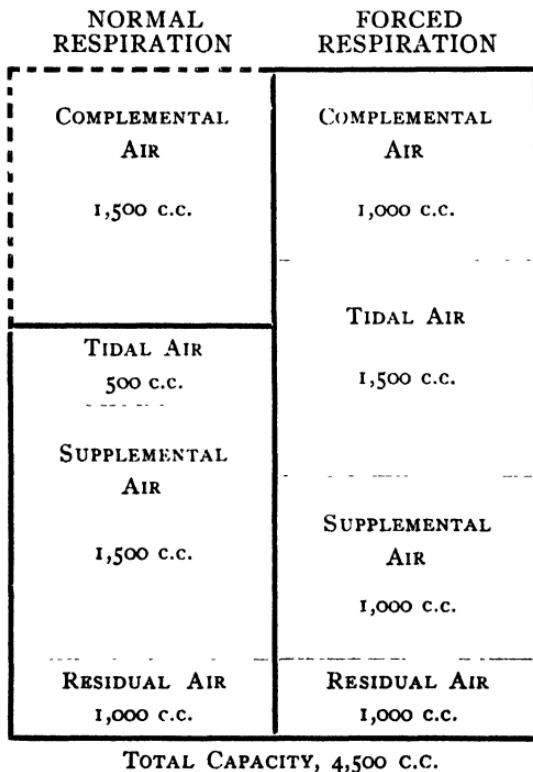


Fig. 124.—Lung Volumes in Normal and Forced Respirations.

In the latter case note how the complementary and supplemental air gradually become tidal air. All values given are approximate, varying greatly among different individuals.

and supplemental air—about 3,500 c.c. A knowledge of this value is of diagnostic importance in clinical medicine.

TOTAL VENTILATION is the volume of air breathed per minute, usually between 5 and 10 litres in the adult. In exercise it increases rapidly, and in the severest of exercise may reach 100 litres per minute.

An average oxygen consumption in the resting condition is about 250 c.cm./min., with an output of 215 c.cm./min. of CO₂, giving an R.Q. of 0.86.

SUMMARY

RESPIRATION—all those processes concerned in the exchange of O₂ and CO₂ between an organism and its environment.

- a. **External respiration**—a mechanism to get O₂ in, CO₂ out of the capillaries.

Branchial in fishes, pulmonary in all vertebrates except fishes, cutaneous and pulmonary in frogs.

- b. **Internal respiration**—exchange of O₂ and CO₂ between capillaries and tissues (*via* lymph and tissue fluids).

COMPOSITION OF INSPIRED AND EXPIRED AIR (per cent.).

	Inspired air.	Expired air.	Alveolar air.
Oxygen	20.96	16.4	14.0
Nitrogen	79.00	79.5	80.5
Carbon dioxide	0.04	4.1	5.5
Water vapour	Variable	Saturated	Saturated
Temperature	Variable	34.0° C.	37.0° C.

ASPHYXIA—a failure (partial or complete) of respiration.

May be due to any one of a large number of possible causes.

Three stages (in animals)—hyperpnoea, leading to expiratory convulsions, and exhaustion.

OF CLINICAL IMPORTANCE, are :—

- a. The respiratory rate (16/min.), especially heart rate resp. rate.
- b. The vital capacity (3,500 c.c.), particularly in cardiac disease.
- c. The total respiration (5 litres/min.) ; R.Q. about 0.85.
- d. Normal O₂ intake, 250 c.c./min. ; CO₂ output, 200 c.c./min.

CHAPTER XXVII

PULMONARY RESPIRATION

THE PULMONARY RESPIRATORY APPARATUS

consists of the following parts :—

1. **A large aerating surface** for the rapid intake, by diffusion, of oxygen into the blood capillaries, and the output of carbon dioxide from them. This is secured by arranging that the capillaries lie in the very thin walls of the pulmonary alveoli.

2. **Accessory apparatus** consisting of a series of tubes (nose, pharynx, larynx, trachea, bronchi, bronchioles) to convey the air to and from these alveoli and also an automatic muscular mechanism to produce this passage of air.

3. **A controlling mechanism**, both nervous and chemical, to regulate the degree of ventilation and to co-ordinate it with that of the body in general.

The pulmonary alveoli and accessory apparatus have already been described in Chap. XII. We will now consider the muscular and controlling mechanism.

THE AUTOMATIC MUSCULAR MECHANISM.—The **walls of the thorax or chest** are formed by the twelve thoracic vertebræ behind, the *breast bone* or *sternum* in front, the *ribs* with their *intercostal muscles* around the sides, and the membranous and muscular *diaphragm* below. It has a conical shape and is somewhat flattened from before backwards. The heads of the ribs form *movable joints* with the dorsal vertebræ, and the other ends of the ribs are connected in front with the sternum by the flexible *costal cartilages*. The lungs fill the greater part of the conical cavity of the thorax—excepting the small portion occupied by the *lower trachea*, the *œsophagus*, and the *heart* with its *great vessels* and *pericardium*. They are enclosed in a double membrane—the *pleura*—one layer of which, known as the *visceral pleura*, is firmly attached to the outer surface of the organs, and dip into the fissures between the lobes, while the other lines the cavity of the chest, being closely adherent to its walls. This latter portion is known as the *parietal pleura*.

Thus the chest is an air-tight cavity, having no *direct* communication with the atmosphere ; while the lungs may be considered as bags filling this cavity, being themselves filled out with air which enters through the trachea.

Although in fig. 78 a space is represented between the two layers of the pleura, this is not actually the case, the space being inserted only for the sake of distinctness : the two layers of the pleura are in contact with each other, there being nothing between them save a very little watery fluid (*lymph*) which is secreted by the membrane, and only sufficient of this to allow of a free gliding motion during the respiratory movements of the chest and lungs. Such a secreting closed sac is called a *serous membrane*.

Thus the space between the pleura, although merely a potential one, is known as the pleural cavity. In the condition known as **empyema** this cavity is filled with pus and the pleura is inflamed, the parietal and pleural layers being separated. **Pleurisy** is inflammation of the pleura, often accompanied by adhesion of portions of the visceral and parietal layers.

RESPIRATION is the result of the alternate expansion and contraction of the walls of the chest. In **inspiration** (Lat. *in*, and *spiro*,

I breathe) we enlarge the chest by means of certain muscles, and so tend to produce a vacuum (an empty space) between the lungs and the chest ; and, as a natural result, air (*i.e.* the tidal air) rushes in through the trachea, thus causing the lungs to expand with the chest. When these muscles cease to contract the elasticity of the bony and cartilaginous thoracic wall, and also that of the lungs, causes the thorax to return to their former volume, aided by the contraction of a set of muscles antagonistic to those producing inspiration ; therefore the air taken in is expelled again. This is the

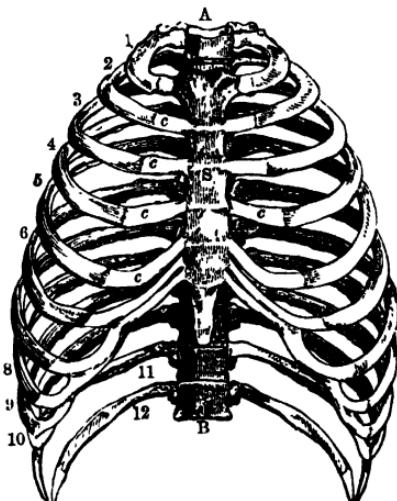


Fig. 125.—The Framework of the Chest.

A, first dorsal vertebra ; B, last (12th) dorsal vertebra ; 1 to 12, ribs ; S, sternum ; C, costal cartilages.

act of **expiration** and the lung movements are very largely passive.

Fit up an apparatus as represented in fig. 126, in which A is a stout glass tube, provided with a sound cork, B, and also an airtight piston, C, resembling that of an ordinary syringe. A short tube, D, passing through the cork, has a small indiarubber bag tied to it. Fit the cork in the tube while the piston is near the top. Now, by lowering the piston we increase the capacity of the cavity containing the bag. The pressure outside the bag is thus lowered, and air rushes into it through the tube D till a balance is restored. The bag is thus stretched. As soon as we let go the piston the elasticity of the bag, being free to act, drives out the air just taken in, and the piston returns to its former place. It will be noticed that in this experiment the elastic bag and its tube represent the lungs and trachea; and the vessel enclosing it, the thorax.



Fig. 126.—Apparatus for illustrating the Movements of Respiration.

THE RESPIRATORY MECHANISM.

—We have now to study the mechanism by which the chest is made to contract and expand.

Inhalation is a co-ordinated muscular act by which the cavity of the chest is *widened* and *deepened*. The latter result is brought about by the contraction of the **diaphragm**, which causes it to become less arched. This causes the lower portion of the sternum to move forwards and so increases the thorax from front to back, *i.e.* antero-posteriorly. Also the ribs move slightly outwards, and so enlarges the diameter of the thorax from side to side. Finally, since the diaphragm moves downwards (driving also the ~~contents~~ of the abdomen downwards and forwards), the vertical diameter of the thorax is increased. Hence we see that the volume of the thoracic cavity is increased in *all* directions. The dia-phragm and the posterior cricoarytenoid are

to be regarded as the most important muscles of inhalation. The latter separates the vocal cords, and so opens the glottis to allow air to enter the trachea.

The **intercostal muscles**, of which there are eleven on either side, connect the adjacent ribs throughout their length. They consist of two thin layers of oblique muscular fibres which occupy the spaces between the ribs. These layers are termed

respectively, the *internal* and *external*. The **internal intercostal muscles** pass obliquely *downwards* and *backwards* from the lower margin of one rib to the upper margin of the next, as seen from the front of the chest. They depress the ribs, make the chest narrower and so assist expiration. The **external intercostal muscles** incline *downwards* and *forwards*, at least on the front surface of the chest, and are much stronger and thicker than the internal. They *raise* the ribs, widen the cavity of the chest, and thus assist *inspiration*. It should be mentioned that some consider the intercostals to have but little effect on respiration, their object being to act as an elastic wall.

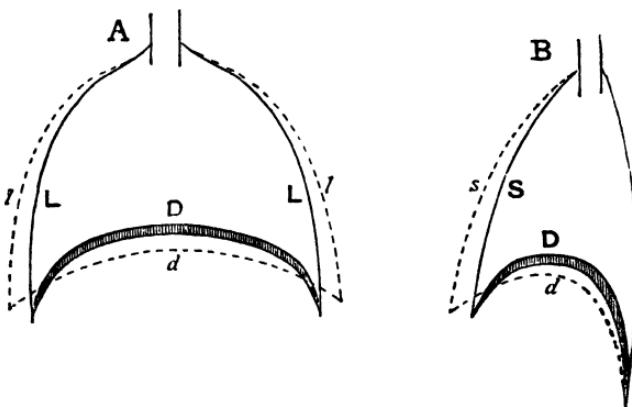


Fig. 127.—Diagrams to illustrate the Enlargement of the Thorax during Inspiration.

A, vertical section, front view; B, vertical section, side view: D, d, diaphragm; L, l, lateral walls of chest; S, s, sternum

We are now better able to understand the **respiratory movements**, which may be briefly described as follows:—

During **inspiration** the **diaphragm descends**, making the chest *deeper*; and the **external intercostals contract**, thus raising the ribs and making the chest *wider*. The capacity of the chest being thus enlarged, the pressure is reduced, and air rushes in so that the lungs are inflated.

In **tranquil breathing** the **inspiration** of air is effected chiefly by the **diaphragm** in men, while in forced inspiration the muscles of the trunk and neck are called into use. In some women the diaphragm is much less used than the ribs, and their breathing is therefore of the thoracic type. In young children of both sexes breathing is abdominal.

As the ribs are raised during inspiration, the sternum will of course rise with them. This movement may be noticed by laying the hand on the front of the chest while taking a deep inspiration. Again, when the diaphragm moves, the organs of the abdomen must follow its movements, and this causes a visible motion of the walls of the abdomen. Hence respiration which is effected chiefly by the diaphragm is often termed **abdominal respiration**, while that produced mostly by movements of the side walls of the chest is called **costal or thoracic respiration**.

The diagram is an actual tracing taken of the respirations of a cat, while under an anæsthetic.



Fig. 128.—Record of Respiratory Movements made by an Anæsthetised Cat.

Upstroke = inspiration ; downstroke = expiration.

Expiration.—As a result of the inflation of the lungs by the inspired air they are stretched, and their **elasticity** is probably sufficient in quiet breathing to expel the air without the aid of any muscles. But some consider that expiration, too, is brought about by contraction of muscles which are antagonistic to those which produced inspiration. It has been shown that there is a co-ordination between antagonistic groups of muscles in other parts of the body, and there is no great reason why the respiratory muscles should be an exception to this rule. But in a **forced expiration** the **internal intercostals** are brought into play, and also the **muscles of the abdomen**, which latter act on the organs of the abdomen, thus exerting indirectly an upward pressure on the diaphragm.

Although the **respiratory movements** are generally purely *involuntary*, yet they are brought about by muscles which are under the control of the *will*; and are sometimes partially or entirely *voluntary*, as in speaking, singing, blowing and asphyxia.

SPECIAL RESPIRATORY EFFORTS.—We may now notice some of the more important respiratory acts which differ from ordinary breathing. Generally speaking, while respiration is going on, the *glottis* (the aperture at the upper end of the trachea) is open so as to allow a free passage to the air. In *speaking* or *singing* the *vocal cords* are stretched across the larynx, leaving only a narrow space, the *glottis*, for the passage of air. Under these circumstances the cords are made to vibrate by the air current forced between them, thus producing those sounds which are known as the *voice*.

A **sigh** is simply a prolonged inspiration, followed by a rather sudden expiratory movement. The former is produced chiefly by the action of the abdominal muscles, and the latter is due to the elastic recoil of the lungs and the walls of the chest. Sighing is exhibited by some animals (dogs) and sometimes by patients when anaesthetised, apart from natural mental emotions.

Hiccup is a sudden inspiration, produced by the spasmoidic action of the diaphragm. Being so sudden, the aperture of the glottis is unprepared for the rush of air, and hence the peculiar sound produced by the vibration of the vocal cords. It is usually due to irritation of the vagal nerve ends in the gastric mucous membrane.

Coughing is generally preceded by a deep inspiration. The glottis is then closed firmly by the muscles of the larynx, and the expiratory muscles suddenly contract. At first the force is not sufficient to open the glottis, but at last the vocal cords are suddenly burst open, and the air is noisily expelled. Coughing is a means by which any mucus, foreign body, or other matter which irritates the walls of the air passages may be got rid of.

Sneezing is produced much in the same way as coughing, *i.e.* a deep inspiration followed by a sudden sharp expiration, but the tongue is raised against the soft palate so as to divert the air current through the nasal passages instead of the mouth.

Laughing consists of a prolonged inspiration followed by short and rapid expirations. If particularly loud and hearty the diaphragm is called into action very vigorously. A really good diaphragmatic laugh is one of the best of tonics.

Yawning is a long inspiratory act, accompanied by a stretching of the muscles of the mouth and face. It is often a symptom of want of fresh air, indigestion or tiredness.

Crying consists of short and sudden expirations, with long inspirations, and accompanied by tears and more or less grotesque facial contortions.

THE CONTROLLING MECHANISM is both chemical and nervous. There are a series of respiratory centres in the floor of the fourth ventricle which control breathing. They are affected by the O₂ want, by the CO₂ content of the blood, and by nerves which run to it from the lungs and aorta.

1. **Chemical Control.**—It has been found by experiment that if the percentage of CO₂ in the inspired air is increased, the depth and frequency of the respirations are both increased to such an extent that the CO₂ percentage in the alveolar air still remains constant. Similar remarks apply when the O₂ percentage is reduced. This shows that oxygen deficiency and particularly CO₂ excess both act as stimulants to respiration.

2. **Nervous Control.**—Any sensory stimulation affects respiration reflexly. Afferent fibres run with the vagus from the alveoli which also affect breathing. Changes in blood pressure can also reflexly alter breathing. By our own voluntary efforts we can—for a short time—hold our breath until the alveolar CO₂ rises to 8 per cent. Then the chemical control becomes too powerful, and we are forced to breathe.

Briefly, one may say that respiration is so regulated that the reaction of the blood is kept constant.

SUMMARY

THE PULMONARY RESPIRATORY APPARATUS :—

1. A large aerating surface—the alveolar walls, lined by capillaries.
2. Accessory apparatus—of a mechanical nature.

a. A tubular system conveying air to and from alveoli.

Nose → pharynx → larynx → trachea →

bronchi → bronchioles → atrium → alveoli.

b. Muscular mechanism for periodic conveyance of air in and out.

3. A controlling mechanism—by action on the respiratory centres in the floor of the fourth ventricle.

Object is to preserve constancy of reaction of the blood.

a. Chemical—by the CO₂ content of the blood, or its O₂ lack.

b. Nervous—by afferent vagal impulses from lungs and aorta.

INSPIRATION—an active, usually involuntary muscular act.

Chest enlarged in three dimensions—depth, width, height.

Muscles used—external intercostals and diaphragm.

Air enters lungs, for pressure outside is greater than inside.

EXPIRATION—capacity of chest decreased, largely by passive recoil.

Quiet expiration—diaphragm raised.

Forced expiration—in addition, abdominal muscles contract.

Abdominal organs pressed against diaphragm, and in both cases air is forced out of the lungs.

CHAPTER XXVIII

THE SKIN

THE SKIN or **integument** is that which covers the whole of the body. It is a special sense and glandular organ, consisting of two layers, the *epidermis* and the *dermis*.

1. **THE EPIDERMIS** (Gr. *epi*, upon; and *derma*, the skin), **cuticle**, or **scarf-skin**, covers every part of the *dermis* or **true skin**. It is hard and horny, and composed of minute scales which are being continually worn away from the surface.



Fig. 129.—Magnified view of the Epidermis, showing the Pores.



Fig. 130.—Thumb-prints (left and right).
The openings of the sweat ducts (pores) may be seen with the aid of a small hand lens.

Histologically it is a thick stratified squamous epithelium. The thickness of the epidermis varies in different parts. In the palms of the hands and the soles of the feet—parts which are much exposed to great pressure—it is as much as 1 mm., while in some parts the thickness is less than 0.1 mm.

The surface of the epidermis presents a multitude of minute openings when viewed with a magnifying glass. These are the **pores** of the skin, and are in reality the openings of the

ducts of little glands which excrete the sweat or perspiration.

The diagram (fig. 130) is of two thumb-prints. It shows on examination with a hand lens the openings of the sweat pores. Incidentally it also shows the nature of the loops, whorls, arches and composites, the peculiar nature of which constitutes the "finger-print tests" in the investigation of crime.

The epidermis itself contains no blood-vessels and but few nerves, its office being largely to protect the deeper layer of the skin. If we thrust a needle through the epidermis without penetrating the dermis beneath, we feel no pain and shed no blood; but, as soon as the dermis or true skin is injured, we feel a sharp sensation of pain, and more or less blood flows.

The internal cavities of the body are all lined with a soft, pinkish membrane called the **mucous membrane**; and this is continuous with the skin at the margins of the lips, the nostrils, the eyelids and anus.

The deeper portion of the epidermis, which connects the outer, horny layer with the true skin, is softer and less transparent. It is made up of minute cells, some of which contain pigment granules known as **melanin**. Healthy skin is always more or less pinkish in colour. This is not due to the pigment cells, but to the presence of blood capillaries in the *dermis*, the colour of the blood being seen through the transparent epidermis. We sometimes describe the skin as "dark" or "fair," "tawny" or "blonde"; and in these instances the differences in the tint are due to the amount of pigment in the cells of the *pigment layer*. In the European this amount is generally small; it is greatest in the skin of the negro. The pigment layer of the skin is also called the **rete mucosum**.



Fig. 131.—Vertical Section through the Skin of a Negro. ($\times 250$)

a, dermis, or true skin; *b*, *c*, undermost layer of the epidermis; *b* represents the dark layer of pigment cells; *d*, epidermis, composed of horny scales.

(mucous net), or the Malpighian layer, from its discoverer (Malpighi).

The cells of the **rete mucosum** are nourished by the blood which circulates in the dermis. They are also being continually pushed outward by the growth of new cells beneath (forming the **stratum granulosum**) ; and, as they approach the surface, the pigment disappears, and they become almost transparent, forming the **stratum lucidum**. These become gradually more and more horny, being, in fact, converted into horny scales which take the place of those which are continually worn off by friction from the outer

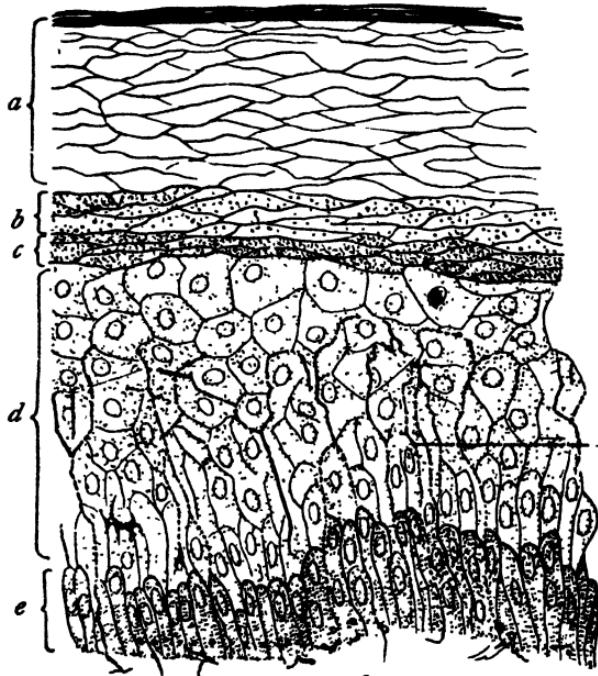


Fig. 132.—The Epidermis (human).

a, stratum corneum; *b*, stratum lucidum; *c*, stratum granulosum;
d, stratum mucosum; *e*, stratum germinativum.

layer. This superficial layer of dead cells is known as the **stratum corneum**. The disappearance of the pigment in the superficial portions of the skin is not easy to explain. A blister in a negro's skin is white, and also in old age his hair becomes white, though his skin remains black.

The skin serves to protect the living tissues beneath it against the absorption of poisons, the entry of micro-organisms, and also from moderate violence. If the skin is unbroken poisonous substances may be freely handled ; but they are readily absorbed into the blood when the cuticle is cut, or

when a small portion of it has been torn off. In a similar way it also serves to prevent the moisture of the tissues from oozing outwards and so being lost by evaporation. The skin therefore acts as a waterproof envelope.

2. THE DERMIS, true skin (*cutis vera*), or **corium** consists of fibres of *collagenous* and *elastic tissues*, interwoven with minute blood-vessels and nerve fibres. Its surface is drawn up into finger-like projections called **papillæ**, the largest of which are about $\frac{1}{100}$ of an inch in length and arranged in rows, as explained above in connection with finger-prints. The outer portion is extremely well supplied with blood-vessels. Every papilla has its loop of capillaries, and, in some cases, special nerve ends concerned with the sense of touch.

The deeper portion of the dermis is looser in texture, and contains an amount of fatty tissue. Beneath this again is a loose cellular tissue—the **subcutaneous tissue**—which contains a large proportion of fat. The use of this latter tissue is to fill up all the irregularities of surface in the underlying parts, and to give the rounded form and plumpness to the surface of the body. The **fatty tissue** also, being a bad conductor of heat, serves to keep the body warm by preventing the outward passage of heat.

The **sensitivity of the skin** as the organ of *touch* is due to the distribution of nerve fibres which terminate in the papillæ of the dermis. There are certain special sense organs in which the nerve fibres terminate. Collectively they are known as **tactile corpuscles**. These nerve-endings vary considerably in form, and possibly also in function, and will be described in a future chapter.

APPENDAGES OF THE SKIN.—There are certain outgrowths of the skin to be considered, viz. the sweat glands, nails, hairs, sebaceous and mammary glands.

(i) **The sudoriferous glands.**—The **pores** of the skin have already been mentioned as the openings of the ducts of the **sweat glands**. These openings occur on the ridges seen on the free surface of the epidermis, each pore lying between

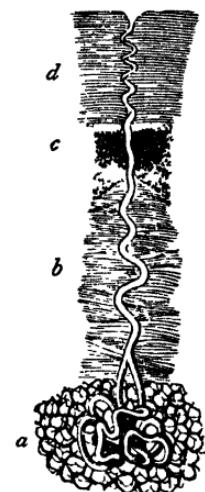


Fig. 133.—Magnified view of a Sweat Gland, with its Duct.

a, the gland surrounded by fat-cells; b, the duct passing through the dermis; c, its continuation through the reticular mucosum, and d, through the upper epidermis.

neighbouring papillæ. By making a section of the skin we are enabled to trace these **ducts** to the deeper portion of the dermis, where the glands are situated. As the ducts pass through the epidermis they are twisted like a corkscrew. On reaching the deeper layer of the dermis, or, sometimes, on entering the subcutaneous tissue, the ducts are coiled up into little balls. These little bodies constitute the **sudoriparous** (Lat. *sudor*, sweat; *pario*, I produce) or **sweat glands**. Each gland is surrounded by a dense network of blood capillaries, giving it the appearance of a reddish ball. As the blood circulates through these vessels the fluid which we call the **perspiration** or **sweat** is separated from it, passing up the duct till it reaches the surface of the skin. Here the sweat is gradually evaporated away, cooling the skin in so doing.

There are very large sweat glands in the axillary, genital and mammary regions, which only develop at puberty. They may be considered as forming part of the secondary sexual characters.

Sweat consists of 99 per cent. water and 1 per cent. solids, mostly urea and inorganic salts (common salt being the most abundant). It has been estimated that about 600 c.c. of sweat are excreted daily. The excretion is continuous, most of it leaving the skin at once by the process of evaporation, and known as insensible perspiration. If the atmosphere is very humid, or if the sweat is produced very rapidly, it remains for a while as drops of fluid, and is then known as sensible perspiration.

It is important to realise that sweat secretion is under nervous control, for the special purpose of regulation of the body temperature. A local increase of blood supply, as a hot bath, will of itself increase the sweat secretion, but this is not always necessary. For example, in scarlet fever the skin is flushed yet dry, while in collapse it is white and wet.

From what has been said, it is clear that we must look upon the skin as an **excretory organ**—that is, one by which waste materials are separated from the blood circulating in it. Like the lungs, it is a source of loss to the blood ; but while the lungs give off a great amount of carbonic acid gas and water vapour, the skin excretes but little carbonic acid gas. It is also a secretory organ, as witness the sebum of the sebaceous glands, and the cerumen or wax of the external auditory meatus.

The chief use of the perspiration is the protection of the body from too high a temperature, or, in other words, to keep the body temperature constant. When the surface of

the body is cold, the supply of blood to the skin is decreased by the contraction of involuntary muscular fibres which reduce the size of the blood-vessels. At the same time the ducts of the sweat glands are contracted, and consequently the secretion of the perspiration is slow. But when the body becomes overheated by exercise, or when the surface of the body is exposed to great heat, the muscles of the skin relax, the supply of blood increases, the gland ducts open wider, and the perspiration is given off freely. The evaporation of this moisture tends to reduce the temperature of the skin, and consequently that of the body.

The relation between the functions of the skin and the kidneys may also be noticed from the fact that in summer, when the skin is active, the excretion of the kidneys diminishes ; and *vice versa*.

There appears to be special sub-centres in the spinal cord for the regulation of sweating, with probably a controlling higher centre in the medulla. Drugs which produce sweating are called **diaphoretics** (Gr. *diaphorein*, to carry off) or sudorifics, such as pilocarpine, salicylates and emetics.

(2) **The nails** (Lat. *ungues*) are simply a thickening of the deeper parts of the horny layer (*stratum lucidum*), growing over the *rete mucosum* which forms their bed. At the "root" of the nail the skin is folded back on itself, so that two layers are facing each other ; thus the nail at this point grows by additions of epidermic cells *above*, *below* and *behind* ; the new growth above and below adding to the *thickness* of the nail, while additions received behind continually push it forward. The nail continues to receive additions in its thickness on the under surface as long as it remains attached to the skin below it.

(3) Each **hair** (*pilus*) consists of a *root* or *bulb* and a *shaft* or *stem*. The **root** is embedded in a recess of the skin called the **follicle**, which is formed by a layer of the dermis, lined with a thin continuation of the *rete mucosum*. Around the hair follicle is a plexus of nerve fibrils which helps to make the skin still more sensitive, for the hairs can therefore act as sensory organs. These two layers form a **sheath** which invests the root of the hair so closely as to be often pulled out with the hair. From the bottom of the follicle there rises a small **papilla** supplied with blood-vessels and nerves. This is the growing point from which the hair is pushed forward by continual additions. The **shaft** of the hair is, like the epidermis, devoid of blood-vessels and nerves. Hair is found all over the

surface of the body with the exception of the eyelids (outer surface), palm of hand, sole of foot, and parts of the genital organs. The colour of hair is due to pigment granules in the medullary portion. In the absence of pigment the hair is white.

Hairs are provided with **muscles**, each muscle being known as an **arrector pili** (Lat. *arrigo*, I raise ; *pilus*, a hair). These are composed of involuntary fibres, and pass from the side towards which the hair slopes obliquely to the outer layer of the dermis. It is evident, therefore, that when they contract, under the influence of cold, fear or adrenaline, they tend to make the hair more erect. This causes a roughening of the whole skin producing a condition of "goose skin." It also squeezes out some of the **sebum**. There are nerves which supply these

muscles ; they are called "*pilo-motor*" and belong to the sympathetic system (see Chap. XXX).

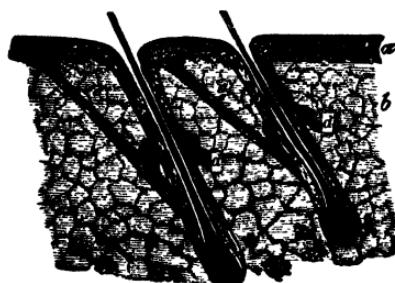


Fig. 134.—Section of the Skin, showing the Hair Follicles, Sebaceous Glands, and the Muscles of the Hairs.

a, epidermis ; *b*, dermis ; *c*, muscles of the hair follicles ; *d*, sebaceous glands.

sebaceous glands are most abundant wherever there are hairs. They are absent in the palm of the hand and sole of the foot. Sebum is acid in reaction, due to fatty acids, and this probably accounts for its objectionable smell.

In some persons there is an excessive secretion of sebum, which condition is known as **seborrhœa**. It is most often associated with increase of sweat or hyperhidrosis (Gr. *hyper*, over ; *hidros*, sweat).

The absorptive power of the unbroken skin is very slight or even nil, any effects observed being probably due to absorption *via* the sweat ducts and hair follicles. It is found that some slight degree of absorption of drugs through the skin may be obtained by incorporating them into lard, lanoline or goose grease, *i.e.* by using an ointment. This method of administering

(4) **The sebaceous glands.**—Each hair is provided with small glands which secrete an oily fluid to lubricate the hair and the surrounding skin. These are called the **sebaceous glands** (Lat. *sebum*, suet). They consist of little saccules communicating with a common duct which opens into the neck of the follicle. The

a drug is known as inunction. Of course, if the skin has been removed, as in an abrasion, or a raw wound, considerable absorption is possible and can easily become a source of danger. Iodine painted on the skin can be afterwards detected in the urine.

The skin, especially the deeper layers of the corium, also serve as a natural storehouse for water and fat. The former is readily lost in a severe attack of diarrhoea or in thirst, while the latter is continually varying according to diet.

(5) **The mammary glands** are only functional after pregnancy.

SUMMARY

THE SKIN—that which lines the surface of the body In two parts:—

- a. **Epidermis**—protective, nerveless, constantly renewed.
- b. **Dermis**—vascular, fat deposits. Thrown into ridges.
 - Nerves (pain, touch, heat, cold).
 - Glands—sweat and oil (sebum).
 - Muscles—arrectores pilorum—contraction causes goose skin.

Glands—for sweat, oil, milk.

- a. Sudoriferous—coiled tube in dermis. Ducts form the “ pores.”
- b. Sebaceous—oily fluid to lubricate skin and hairs.
- c. Mammary—secrete milk, for nourishment of the baby.

Epidermal structures—outgrowths of the skin.

- a. Nails—horny thickenings of stratum corneum.
- b. Hairs—epidermal growths from deep pits (hair follicles).

In association with sebaceous glands and hair roots are the arrectores pilorum, which make the hairs stand upright.

- c. Glands—sudoriferous, sebaceous, mammary.

Nervous structures—associated with special sense organs.

Tactile corpuscles, of several types—Pacini, Krause, Meissner.

Perspiration—more than 99 per cent. water, with a trace of NaCl.

700 c.c. daily, but largely dependent on climate, clothing.

Keeps temperature constant, by heat loss from sweat evaporation.

Functions.

1. Protection—temperature change, injury, loss of body fluids.
2. Sense organs—touch, heat, cold, pain.
3. Excretion—water, salts, trace of urea.
4. Secretion—sebum, cerumen.
5. Absorption—slightly, hence use of ointments.

CHAPTER XXIX

THE KIDNEYS AND RENAL EXCRETION

ANATOMY.—The kidneys, two in number, are situated at the back of the abdomen, one on each side of the three upper

lumbar vertebrae. They are deeply seated in the loins, behind the *peritoneum*, and are held in this position by their own vessels, and by a quantity of *areolar tissue* which usually contains much fat. They measure about 4 inches in length, $2\frac{1}{2}$ inches in width and $1\frac{1}{4}$ inches in thickness, their weight being about 5 ounces each (or 150 grams) in the male, and slightly less in the female.

The kidneys are arranged with their concave surfaces directed towards the vertebral column; and the right kidney, which is usually shorter and thicker than the left, is generally a little lower, probably on account of the downward extension of the large right lobe of the liver. The right kidney lies against the last right rib, and the left against the eleventh and twelfth left rib.

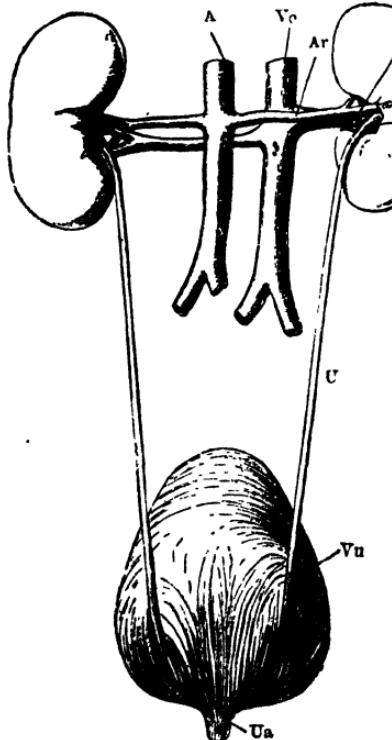


Fig. 135.—The Kidneys, Bladder, and their Vessels, viewed from behind.

r, right kidney; u, ureter; A, aorta; Ar, right renal artery; Ve, vena cava inferior; Vr, right renal vein; Vu, bladder; Ua, commencement of urethra.

rib, and the left against the eleventh and twelfth left rib.

The surface of the kidney is smooth, and of a deep red colour. It is covered with a thin fibrous coat—the **capsule**—which invests the organ closely, but which can easily be detached.

In the concave surface of the kidney there is a longitudinal depression called the **hilus**, at which the vessels and nerves enter and leave. It is here that the capsule of the kidney becomes continuous with the outer coat of the ureter. The concavity of the kidney is usually filled in with areolar and fatty tissue, through which the vessels pass to and from the organ; and by carefully removing this substance **three vessels** may be traced to their entrance into the kidney.

These **vessels of the kidney** are (1) the **renal artery** (Lat. *renes*, the kidneys), which conveys oxygenated blood direct from the descending branch of the *aorta*; (2) the **renal vein**, which collects the blood that has circulated in the capillaries of the kidney, and carries it direct to the *ascending or inferior vena cava*; and (3) the **ureter**, which carries away the fluid secreted from the blood, and conveys it to the *bladder*. The relative position of these vessels in the hilus is as follows: the vein is in front, the artery next, and the ureter is most posterior. By this means one kidney can be differentiated from its fellow of the opposite side.

We must now study a **longitudinal section of the kidney**. A clean cut should be made from the outer convex surface straight through to the hilus. It will be noticed that the ureter leads from a cavity with a number of short, wide prolongations. The cavity is called the **pelvis** of the kidney, and its branches, **calices** (Lat. *calyx*, a cup). We also observe that the solid portion of the kidney consists of an inner **medullary**

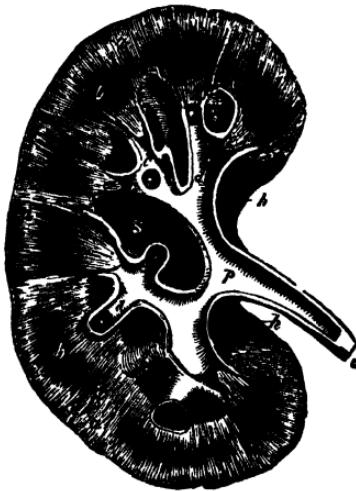


Fig. 136.—Longitudinal Section of the Human Kidney. ($\times \frac{1}{2}$)

a, cortical substance; *b*, pyramids—broad portions; *c*, calyces of the pelvis laid open; *c'*, calyx, unopened; *d*, summits of the pyramids projecting into calices; *e*, narrow parts of pyramids; *p*, pelvis; *u*, ureter; *h*, hilus; *s*, extension of the hilus.

substance which has a fibrous appearance, and an outer cortical substance of a light brown colour.

The medullary substance is not really fibrous, but consists of a multitude of minute tubes arranged in separate conical masses called the pyramids, there being eight to twelve of them in a human kidney. The apex or point of each pyramid is turned toward the pelvis of the kidney, into which it projects, presenting a number of minute openings which are the terminations of the little tubes of the pyramid. By squeezing the cut kidney, a little watery fluid may be made to drain from these tubes into the pelvis. The cortex has a granular appearance, with a number of radiating lines.

From this cursory examination of the kidney it would appear that the blood from the renal artery is abundantly supplied to the cortical portion of the organ (hence the dark colour), where a process of excretion goes on, and that the watery fluid (the urine) there separated passes through the minute tubes of the pyramids into the pelvis, whence it is conveyed to the bladder by the ureter. This is actually the case; but in order to understand how this is brought about it will be necessary to give a more detailed examination, aided by the microscope.

If we examine a thin prepared section of the kidney under a powerful microscope, we notice that the straight tubes of the pyramids (the uriniferous tubes) radiate towards the cortical portion, branching as they go. On reaching the cortical layer they are distributed irregularly, interlacing each other, and commence in little expansions called Bowman's capsule. Those globular enlargements form the granular appearance of the cortex, while the uriniferous tubules constitute the striated character already mentioned. Into each capsule a small branch of the renal artery enters, forming a tuft or ball of capillaries which nearly fill the cavity of the capsule. This capillary tuft is known as a glomerulus. The blood is then collected up by a small vein, which again breaks up into a capillary network around the walls of the uriniferous tube, and is finally conveyed away through the medullary portion to the renal vein. Thus we have another example of blood passing through two distinct capillary systems before entering the great vein which takes it to the heart.

It is now considered that two processes go on in the kidneys. One is that the fluid in Bowman's capsule is formed by ultra-filtration from the blood which flows through the glomerular capillaries. The other is that this filtrate (which is large in volume) undergoes in the tubules a process of resorption of water and other substances, until the resultant unabsorbed fluid has the composition and character of urine.

THE URETERS are the two tubes which convey the fluid excreted by the kidneys into the bladder. They are about 10 to 12 inches in length. The upper end of each, as we have seen, is expanded to form the pelvis of the kidney. The ureters run

downwards and inwards in front of a powerful muscle known as the **psoas**, and finally enter the bladder. They do so obliquely, and open by slit-like apertures into the cavity of the bladder. This arrangement acts as a natural valve to prevent reflux of urine into the ureters.

THE BLADDER is a very strong oval bag, about 5 inches long, situated when empty in the cavity of the pelvis ; though, strictly speaking, its size, position and relations vary according to the amount of urine it contains. Its walls contain abundant *involuntary muscular fibres*, and it is covered on the back and upper surface, *i.e.* postero-superiorly, by a layer of the

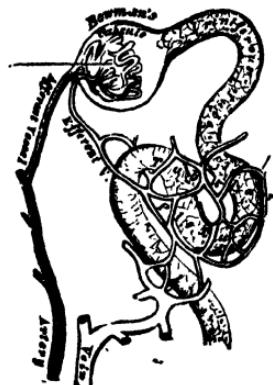


Fig. 137.—The distribution of the Blood-vessels in the Renal Cortex.



Fig. 138.—Diagram of a Glomerulus.

a, afferent vessel; *b*, efferent vessel; *c*, capsule of Bowman; *d*, beginning of tubule.

peritoneum. It has three openings, two of which—the openings of the ureters—have already been mentioned. The third communicates with a duct called the **urethra**, by which the bladder is emptied of its contents. The so-called neck of the bladder, that is, the portion which gives rise to the urethra, is surrounded by a circular (*sphincter*) muscle which is generally in a state of contraction, and thus the passage of liquid from the bladder is prevented. At intervals this muscle is voluntarily relaxed, while the walls of the bladder reflexly contract, and consequently its contents are discharged *via* the urethra.

The secretion of the urinary fluid by the kidneys is continuous, and it passes into the bladder, drop by drop, through the ureters, but only a small proportion of the glomeruli are in action at

any one moment. It will be seen, therefore, that the bladder simply serves to contain the urine so that it may be discharged at convenient intervals from the body. No obstruction is offered to the fluid as it passes from the ureters into the bladder, but it cannot pass backward again into these vessels readily on account of their oblique openings ; and, further, because of small elevations of the mucous membrane at these openings which act as valves. The adult bladder (with moderate distension) will hold about half a pint.

THE COMPOSITION OF THE URINE is usually about 96 per cent. water, and 4 per cent. solids, of which half consists of urea, the chief nitrogenous constituent. The solids consist of organic constituents, chiefly urea, creatinine and urates, while the inorganic portion is composed of sulphates, chlorides and phosphates, chiefly sodium chloride. Sometimes these solids do not remain dissolved, but form granules of varying size, known as gravel, or stones (calculi). They may occur in the kidneys or bladder. There is also present a certain amount of pigment or colouring matter, derived partly from the haemoglobin of the blood, and partly from the colouring matter of food. Urine is of a yellow colour, the depth of which varies with its concentration. Its *reaction*, i.e. its state of alkalinity or acidity, is due to several factors, such as the nature of the food taken, and whether active digestion is proceeding or completed. For example, the urine of carnivora is strongly acid, and that of herbivora and vegetarians is alkaline. Normally it is acid in reaction, due to the presence of acid salts, the most important being acid sodium phosphate, NaH_2PO_4 . The specific gravity varies from 1015 to 1025. In certain diseases there may be abnormal constituents, such as albumin, glucose, bile, blood, acetone and pus.

Note that substances excreted by the kidneys are not formed in these organs, but in other parts of the body.

The **quantity and composition of the urine** vary considerably with circumstances, but it is estimated that the kidneys of a healthy man excrete about 1,500 c.c. per day. The amount, however, is subject to considerable variations, depending on climate, exercise and water intake. Normal urine contains about 60 grams of solids, 25 being inorganic, and 35 grams organic. Of the inorganic 15 grams are common salt, and of the organic 30 grams consist of urea, the rest being ammonia, creatinine and uric acid.

We must therefore look upon the kidneys as great sources of

loss to the blood, and in this respect they are like the lungs and the skin. Of these three losses it is the kidneys only which excrete large quantities of nitrogenous matter.

In studying the work of the kidneys it is most important to appreciate that the essential action is one of **increase of concentration**. That is to say, the constituents present in urine exist in a different strength or concentration (usually higher) than that in the plasma. For example, urea is increased in concentration sixty times, uric acid twenty-five times, while glucose, proteins and fats are absent. This shows that the kidneys are not mere passive agents, for they must do work against opposition, involving the expenditure of energy.

The amount of urine excreted may be increased :—

1. By increased intake of fluids.
2. By cutaneous capillary constriction—as in cold weather.
3. By the use of drugs, called diuretics, e.g. caffeine (coffee).
4. By nervous influences—fear, excitement.
5. By increase in blood pressure.

A decrease can be brought about by conditions the reverse of the above.

The functions of the kidneys are :—

1. To excrete certain waste products already in the blood, especially the nitrogenous substances, urea and uric acid, which are formed during metabolism.
2. To control the reaction and volume of the blood.
3. To control the composition of the plasma, by the elimination of all abnormal constituents, especially toxic substances, or any excess of normal constituents.

MICTURITION.—As urine accumulates in the bladder, the latter expands to accommodate it. When a certain degree of extension is produced varying with different individuals rhythmic contractions begin which act as a warning. Eventually they become so urgent that the urine is voided by a contraction of the bladder walls, and a simultaneous relaxation of its sphincters. This emptying of the bladder is brought about by what is known as a “reflex”—to be explained later. The gradual stretching of its walls sends an equally gradually increasing stimulus along nerve fibres in its walls, to a centre in the lumbar portion of the spinal cord. This centre is itself under inhibitory control by a yet higher centre in the brain. There is therefore delay in the emptying of the bladder until the occasion is convenient, or until opportunity demands it—in spite of social laws.

SUMMARY

KIDNEY	Weight	5 ounces in the male, $4\frac{1}{2}$ ounces in the female.
	Position	At the back of the abdomen—one each side of the upper three lumbar vertebræ.
	Covering	The <i>capsule</i> —a thin fibrous membrane.
	Vessels	Renal artery. A branch of the <i>aorta</i> . Renal vein . . Leads to the <i>vena cava inferior</i> . Ureter . . Conveys <i>urine</i> to bladder. Pelvis . . Commencement of the <i>ureter</i> .
	Structure	Medulla . . Uriniferous tubules, arranged in pyramids. Cortex . . Tubules open on papillæ. Outer darker portion. Contains the glomeruli.
	Excretion (continuous)	1,500 c.c., 33 grams urea. Various salts—NaCl, urates.
	Functions	Excrete waste products—urea and uric acid. Controls the reaction and volume of the blood. Regulates the composition of the plasma.
	Structure	Strong oval bag in pelvic cavity. Involuntary <i>muscular fibres</i> .
	Vessels	Lined with <i>mucous membrane</i> . <i>Ureters</i> —convey urine from the kidneys. <i>Urethra</i> —for the discharge of the urine.
	Uses	To retain the urine, and To discharge it at convenient intervals.

CHAPTER XXX

THE NERVOUS OR CO-ORDINATING SYSTEM

ITS ORIGIN.—In the lowest forms of life (Protozoa) the reaction of one part of a cell to another or the cell to its environment could be made to depend on diffusion, which though slow was sufficient for a unicellular animal. In the case of Metazoa, where the number of cells is increasing as one ascends the scale, the need of communication between one part and another increases. To some extent the use of the vascular system for the transport of hormones (Chap. XXXVIII) helped, but quite

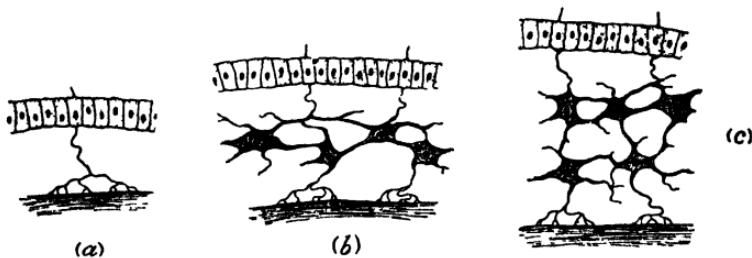


Fig. 139.—Diagrammatic representation of the Evolution of the Primitive Type of Nervous System.

Note the increasing complexity in passing from *a* to *c*.

early on a much more efficient method was developed, viz. the evolution of the nervous system.

It must be clear from the outset that there are two components, namely, the use of the nervous system to enable the animal to respond to alterations in its environment, and its equally important use in the control and co-ordination of all the various systems which make up its body. In brief, we have a set of structures, **receptors**, connected by the nervous system with another set of structures, the **effectors**. By an elaboration of this principle we get the nervous system as developed to the highest extent in man.

AFFERENT AND EF FERENT FIBRES.—It is important to realise that though experimentally we can make a nerve impulse pass either way along a nerve, yet in the body

there is only a one-way traffic along any one nerve. So physiologically we think of two sets of fibres, according as the impulses go to or from the nerve centre. Thus we have :—

1. Those nerve fibres which conduct impulses only *to* a nerve centre are called **afferent** (Lat. *ad*, to ; *fero*, I carry) or **sensory fibres**, because they result in a "sensation." By means of these we are capable of feeling pain or of experiencing any other sensation. For example, when a tuning fork is struck the vibrations are transmitted through the air to the ear, they are taken up by the *auditory nerve* and conveyed to the brain, producing the sensation called sound. Thus the auditory nerve is an *afferent* or *sensory* nerve.

2. Those nerve fibres which convey impulses only *from* a nerve centre are termed **efferent** (Lat. *e*, out ; and *fero*). They are also called **motor**, because their office is to produce motion or secretion.¹ These correspond to the axon. They originate each in a nerve cell, and terminate in muscular fibres, or in gland cells. Each motor fibre may supply a large number of muscle cells. When they receive an impulse from a nerve centre they convey that impulse to the muscle fibres they govern, causing them to contract. Thus, when we hear a sharp sound behind us, we quickly turn the head. The sound vibrations reach the brain as a nerve impulse and there set up a disturbance which is then conducted through the efferent or motor nerves which supply certain muscles of the neck or limbs, and causes them to contract.

Certain terms are in common use, in regard to nerve fibres. A *stimulus* is any means of starting an impulse along a nerve fibre, mechanical such as pinching, chemical as by drugs, and electrical as by a condenser discharge. Some change is thereby produced in the fibre (probably both chemical and physical) known as an "impulse." The ability of the fibre to transmit the impulse is termed its **conductivity**. The effect in the fibre is independent of the strength of the stimulus, though in a **nerve trunk** it would increase (up to a limit) with the stimulus simply because more and more fibres would be called into play.

Some nerves are purely sensory, that is, consist of sensory fibres only. Others consist of sensory and motor fibres, and can consequently convey impulses in both directions, only, of course, not by the same fibres. Such nerves are termed **mixed**.

¹ The terms *afferent* and *efferent* are preferable to *sensory* and *motor*, since the stimulation of the former does not always produce sensation ; nor does motion always result from the stimulation of the latter.

nerves, as, for example, the sciatic nerve of the leg. The nerves which enable us to see, hear, and smell are purely sensory ; but most of the nerves in the body are composed of mixed fibres.

It should also be noted that since nerves are living structures they use up oxygen, and set free CO_2 as a result of the changes going on in them during stimulation. The nerve impulse is not a mere passive affair, decreasing in value as it proceeds, but is kept up to a normal constant value owing to the fact that the fibre is living and contributes at every point to add the requisite amount of energy. All this is summed up in the expression — “all-or-none,” in reference to the character of the impulse. The rate of travel along the nerve is about 120 metres/second depending on temperature. It is almost impossible to tire out a nerve fibre by repeated stimulation. This is due to the fact that after an impulse has passed any point on a fibre, that part is for a short period 1 to 3σ ($\sigma = 0.001$) entirely non-responsive. It is said to have a “refractory period,” during which time it is recovering, ready for the next stimulus, and so on indefinitely.

THE DIVISIONS OF

THE NERVOUS SYSTEM.—On the basis of what has just been pointed out, namely, the two components of the activities of the nervous system, it is natural to consider the system in two parts, that concerned with response to the outside world, *e.g.* sight, sound, etc., and that of the body concerned with the control of the various systems, and their

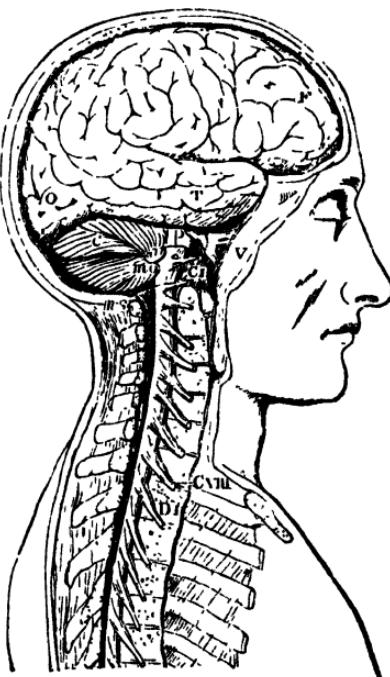


Fig. 140.—Lateral view of Brain and upper part of Spinal Cord after removal of the Membranes.

F, T, O are the frontal, temporal, and occipital lobes; C, the cerebellum; P, the pons; C₁, the first cervical nerve; C_{vii}, is the lowest cervical nerve; D₁, the first dorsal nerve; V, is the 5th cranial nerve.

co-ordination with each other. Each system has its own sets of afferent and efferent fibres. Hence we have the following divisions of the general nervous system :—

1. THE CEREBRO-SPINAL SYSTEM is that which is concerned with the response to outside influences. It consists of a set of receptors (effectors) adapted to the absorption of external energy of different forms, the transformation of the energy into a nerve "impulse" which passes to the cerebral cortex, where it enters our consciousness, and, if necessary, provokes an adequate response *via* its effectors. In this way we have the following components of the cerebro-spinal system :—

(a) **The central nervous system** (C.N.S.)—situated in the central axis of the body. It is made up of the brain and spinal cord (or spinal medulla). The brain is composed of the cerebrum, the mid brain, pons, cerebellum and the medulla oblongata. The extension of the brain downwards is the spinal medulla, more usually known as the spinal cord.

(b) **The peripheral nervous system** (P.N.S.) is composed of the nerves which arise from the brain, the cranial nerves, of which there are twelve pairs, and also thirty-one pairs arising from the spinal cord, and therefore known as spinal nerves.

2. THE AUTONOMIC SYSTEM is that part concerned with the visceral mechanism. From the controlling centre in the thalamus its fibres are distributed to the various viscera—glands, blood-vessels and plain muscle.

The **afferent** fibres, like those of the cerebro-spinal system, go to the sensory root ganglion of a spinal or cerebral nerve. These fibres have not been properly made out.

The **efferent** fibres do not go straight to the effector organ, but proceed to a ganglion, outside the C.N.S., where they are relayed. It is convenient to designate separately the fibres going to the ganglion and the relay fibres proceeding from it :—

Pre-ganglionic fibres (white rami communicantes) are myelinated and come *via* the anterior roots from the lateral horn cells of the cord. At the ganglionic synapse is freed a chemical substance, acetyl choline, by which the impulse is chemically transmitted to the sympathetic relay cell.

Post-ganglionic fibres (grey rami communicantes) are amyelinated. They convey impulses to the effector organs—sweat glands, arterioles and hair muscles, and run with the spinal nerves.

It has been found by experiment that the autonomic system

is subdivided into two functionally antagonistic parts. This we know on physiological and pharmacological grounds, and



Fig. 11.—The Sympathetic Chain of the right side, showing its connection with the principal Cerebro-spinal Nerves.
8*

there is also some anatomical distinction. These sub-groups are :—

(a) **The sympathetic system** consists of two long chains of nerve fibres with their branches and ganglia lying one each side of the vertebral column from the skull to the pelvis. The efferent fibres come from the first thoracic to the third lumbar segments of the spinal cord, *via* the anterior roots.

The effects of stimulation of the sympathetic system are :— Dilation of the pupil, secretion of sweat, erection of the hairs *via* the arrectores pilorum muscles, cutaneous vaso-constriction, thyroid secretion, acceleration of the heart, raising of the blood pressure, broncho-dilation, dilation of the coronary arteries, inhibition of the alimentary system with closure of the sphincters and relaxation of the bladder—in short, adaptation to the needs of muscular activity. All of these effects may likewise be produced by the therapeutic administration (by injection) of adrenaline, for taken by the mouth it has no effect.

There is evidence that stimulation of most of the sympathetic post-ganglionic fibres leads to the freeing of an adrenaline-like substance at the nerve ends, which acts directly on the effector cells.

(b) **The parasympathetic system** originates from the upper (cranial), spinal, and lower (sacral) nerves. The fibres run with the cerebral or spinal nerves. They are found in the cranial nerves (III, VII, IX, X and XI) and in the nerves from the 2nd to the 4th sacral anterior roots.

The effects of the stimulation of the separate components are :—

III. Contraction of the ciliary muscle, and sphincter iridis, for the production of near vision, *e.g.* accommodation.

VII. Secretory and vaso-dilator for the submaxillary and sublingual glands.

IX. Secretory and vaso-dilator to the parotid gland.

X and XI. Cardiac depressor, broncho constrictor, secretory to the stomach, pancreas and gut, inhibitory to the pylorus and ileo-colic sphincter, constrictor to the coronary arteries.

A few myelinated fibres run out *via* the posterior spinal roots to the blood-vessels, and are therefore said to be *antidromic*. They are vaso-dilator, and act by liberation of acetyl choline.

The 2nd to 4th sacral nerves (*Nervi erigentes*) are motor to the rectum, anus and bladder (but inhibitory to the sphincters). They are vaso-dilator to the external organs of generation.

As will be seen, these effects are antagonistic to those of the sympathetic system. All the viscera and organs over which we

have no control have therefore a double nerve supply, the sympathetic and the parasympathetic, with opposite functions. Stimulation of the parasympathetic post-ganglionic fibres leads to the local freeing of acetyl choline at the nerve ends.

SUMMARY

STRUCTURE OF THE NERVOUS SYSTEM.

1. **The neurone**=the anatomical unit.
=Dendrites + nerve cell + axon.
Neurones are of two types, according to direction of conduction :—
 - a. Afferent—carrying impulses to the C.N.S. from a receptor organ.
 - b. Efferent—carrying impulses from C.N.S. to an effector organ.
2. **Synapses**—junctional region between two neurones.
Synaptic transmission is by chemical means.
3. **Fibres**—collections of axons, each covered with neurolemma.
 - a. Myelinated—lipoid sheath covering axon. Function unknown.
 - b. Amyelinated—no lipoidal sheath.

DIVISIONS OF THE NERVOUS SYSTEM.

1. **The cerebro-spinal system**—for adaptation to environment.
 - a. Central nervous system (C.N.S.)—forms central axis of body. Cerebrum, mid brain, pons, cerebellum, medulla, spinal cord.
 - b. Peripheral nervous system (P.N.S.).
Twelve pairs cranial nerves, thirty-one pairs spinal nerves.
2. **The involuntary or autonomic system**—for visceral mechanism.
Controls viscera, blood-vessels, glands, all plain muscle.
Efferent path consists of two neurones—preganglionic (myelinated) and post-ganglionic (amyelinated).
The afferent fibres of this system run with those of the cerebro-spinal system.
 - a. *Sympathetic system*—efferent fibres 1 Th. to 3 L. spinal segments. Produces vaso-constriction, dilation of pupil, accelerates heart, increase B.P., arrests activity of alimentary canal, mobilises glucose, secretes sweat, erection of hairs, broncho-dilator.
 - b. *Parasympathetic system*—not anatomically separate.
Efferents run with cranial nerves (III, VII, IX, X, XI) and the sacral nerves (2, 3, 4). Actions antagonistic to above.

CHAPTER XXXI

THE BRAIN AND THE CRANIAL NERVES

THE ANATOMY OF THE BRAIN.—The brain is the great nerve centre of the body. It is the large upper portion of the cerebro-spinal axis filling the cavity of the cranium. It consists of nerve cells, their processes and a supporting structure, neuroglia, which is a peculiar variety of connective tissue binding together the nervous constituents of the brain.

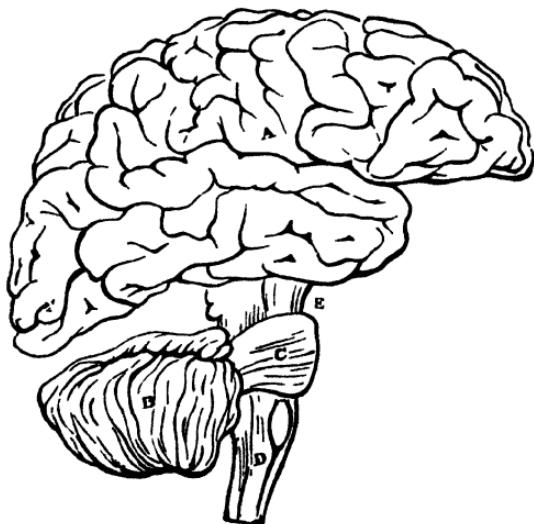


Fig. 142.—The Human Brain (right side).

A, cerebrum ; B, cerebellum ; C, pons Varolii, D, medulla oblongata. The parts are represented as separated from one another somewhat more than is natural so as to show their relation better, x is the mid brain.

The average weight of the adult human brain is about 3 lb., but the size seems to vary very considerably. Cromwell's brain is said to have weighed 2,233 grams, while that of Helmholtz was only 1,430 grams. Mere weight is not in itself of great significance. What appears to be of more importance is the depth of the convolutions.

THE MENINGES are the three coverings or membranes lying between the skull and the brain.

The surface of the brain is covered with a very thin membrane called the **pia mater** (Lat., pious mother), which consists of a network of small arteries and veins, supported by connective tissue. It is from this membrane that the brain receives its supply of blood, and consequently it contains none but very small blood-vessels. The pia mater dips down into the convolutions, and so very closely invests the brain. Outside the pia mater is a delicate and transparent serous membrane called the **arachnoid membrane** (Gr. *arachne*, a spider's web; and *eidos*, form), which consists of bundles of white fibrous and yellow elastic tissue blended together. It does not dip down into the brain fissures (*sulci*) between the convolutions or gyri (Gr. *guros*, a ring). Between it and the pia mater is a space, known as the subarachnoid cavity and is filled with a fluid—the **cerebrospinal fluid**. Over this is a third membrane, the **dura mater** (Lat., hard mother), which is very tough and fibrous. Its outer surface is rough, and in contact with the inner surface of the skull, acting as periosteum, while the inner surface is smooth, and is opposed to the outer surface of the arachnoid, acting as a protective membrane to the brain. It has numerous arteries, veins and nerves.

COMPONENTS OF THE BRAIN.—The brain consists of many parts, the chief of which are :—

1. The **cerebrum** or **greater brain**, which fills all the upper and frontal portion of the cranium, and weighs about nine-tenths as much as the entire brain.

2. The **cerebellum** or **lesser brain**, which lies underneath the posterior portion of the cerebrum.

3. The **mid brain** is the short portion which connects the pons and cerebellum with the cerebrum. It consists of two cylindrical bodies (*cerebral peduncles*), four rounded bodies (*corpora quadrigemina*, two superior and two inferior), and a cavity (*aqueduct of Sylvius*) containing cerebro-spinal fluid.

4. The **pons Varolii** (Lat. *pons*, a bridge), a broad band or bridge of nerve matter which connects the right and left portions of the cerebellum, and the medulla oblongata with the cerebrum.

5. The **medulla oblongata** (Lat., oblong marrow), which connects the pons with the spinal cord—in both directions.

The dura sends projections into the cranial cavity serving to divide it into partitions. These are known as **falces**. One, the falx cerebri, separates the cerebral hemispheres, the falx

cerebelli partly separates the cerebellar hemispheres, while the **tentorium cerebelli** separates the cerebrum and cerebellum.

If we make a section of the brain, we immediately see that it is composed of two parts—a grey and a white. On examination the “grey” matter will be found to consist of nerve cells, neuroglia, and amyelinate fibres, while the “white” matter is mostly made up of myelinated fibres with a little neuroglia. In the cerebrum and cerebellum the grey matter surrounds the white matter, while in the medulla oblongata (and spinal cord) the arrangement is reversed.

Comparative Anatomy.—As one proceeds in the vertebrate kingdom from the fishes upwards, it is noticed that the same general anatomical structure holds good. Any difference is of the nature of a relation between the habits of the animal and the degree to which different parts of the brain has developed. In fishes there is a great development of the olfactory lobes (for smell) and the cerebellum (for equilibration); frogs have very small olfactory lobes and cerebellum; while nocturnal animals have but a small visual cortical area.

We now proceed to study the parts of the brain in more detail.

1. **THE CEREBRUM** consists of two large **hemispheres**, the *right* and the *left*, separated by a very deep fissure—the great longitudinal fissure. It is composed of a layer of grey matter (the *cortex*) surrounding white nerve fibres. The grey matter is drawn up into a number of folds or **convolutions**, by which its surface is greatly increased; and the furrows separating these folds are known as *sulci* or *fissures*. The *pia mater* (which, it will be remembered, is the source from which the substance of the brain is supplied with blood) dips into all the fissures between these folds, and we therefore have reason to believe that the use of this arrangement is to provide the brain with a plentiful supply of blood. The other coats of the brain—the *arachnoid* and the *dura mater*—do not dip into the fissures of the grey matter, but pass straight across them. There are two very deeply marked fissures, which are important landmarks in the cerebral cortex. The fissure of Sylvius is found on the under and outer surfaces of each hemisphere. The fissure of Rolando runs from about the middle of the outer surface of the hemisphere downwards and forwards. The cerebral cortex receives those afferent impulses which enter into and form our consciousness. All our sensations (smell, taste, hunger, thirst, etc.) arise in the cortex, and from its motor cells originate the voluntary movements of the body. There are two irregular

cavities in the lower and inner portions of each hemisphere, known as the *lateral ventricles*, which are in communication with a *third ventricle* lying between them. They all contain cerebro-spinal fluid which connects with that in the central canal of the spinal cord, *via* the aqueduct of Sylvius and the *fourth ventricle* which lies in the medulla.

THE CEREBRO-SPINAL FLUID is produced by certain highly vascular fringes or tufts which project into the *cerebral ventricles*. It is a clear colourless fluid, rather like lymph, alkaline in reaction, and a specific gravity of about 1005. As regards composition, it contains a trace of albumin and globulin, 0·75 per cent. of chlorides, and 0·05 per cent. glucose,

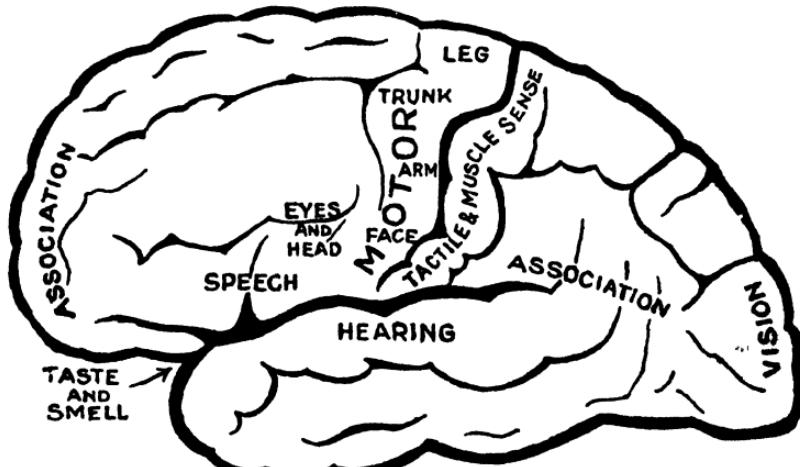


Fig. 143.—Diagram showing localisation of function in the Cortex of the left Cerebral Hemisphere.

and a very few cells like lymphocytes. Marked variations in its chemical or cellular content are of use in diagnosis. It is possible to draw off a specimen for examination by cisternal or lumbar puncture. Cerebro-spinal fluid is said to act as a fluid buffer, to prevent jarring of the nervous system consequent on violent movements of the body, to keep a constant volume of the cranial contents, and to act as a nutrient medium for the nervous system.

THE FUNCTIONS OF THE CEREBRUM.—The cerebrum is the chief seat of *sensation*, *intelligence*, the *will*, *memory* and the *emotions*. When we examine the brains of various animals we notice that the size of the cerebral hemispheres and the complexity of the convolutions are proportional to the intelligence of the animal. Thus, in the rabbit, the cerebrum is small in proportion to the brain as a whole, and its

surface is smooth. In the ape, the cerebral hemispheres are proportionately larger, and their surfaces are drawn up into a number of convolutions ; while in man they are large and still more convoluted. We derive our knowledge of the functions of the cerebrum partly from cases of injury and disease of that organ, and partly from observations on the lower animals. It is found that the principal part of the brain which is concerned with movement is the strip of cortex (precentral convolution) lying just in front of the fissure of Rolando. The movements which are produced by stimulation of any part of this area are limited to the *opposite* side of the body, except such movements as are always bilateral (eyes, jaws, trunk). Note, as always, that these movements are co-ordinated and comprise reciprocal action between antagonistic muscles. If the motor area of one side is damaged, as in a cerebral haemorrhage, there is produced a spastic paralysis of the opposite side. There is, however, a gradual recovery due probably to the fact that motor control is taken over by lower centres. Similarly the area behind the Rolandic fissure gives rise to sensations from skin and muscles.

The various cortical areas that have been mapped out are :—

- (1) Sensory areas—touch and muscle sense are post-Rolandic (post-central gyrus) ; there is a visual centre in the occipital lobe (sensory and psychic) ; an auditory centre in the superior temporal convolution ; one for taste and smell in the hippocampal gyrus ; and there are also “silent” areas—those for which the only assignable function is that concerned with intellectual operations.
- (2) Motor areas—pre-Rolandic, and concerned with volition. The efferent fibres proceeding from this area form the *pyramidal tract*.

At the base of the brain lies several masses of grey matter—the *thalamus* and the *basal ganglia*. It is to the thalamus that all the impulses of **general sensation** reach, where they are felt indistinctly. In most animals this represents their highest sensory centre, so that their sensations are of a crude and imperfect nature. From the thalamus a fresh relay of fibres proceed to the cerebral cortex, where the finer details of sensation enter consciousness.

2. **THE CEREBELLUM** or lesser brain consists of two hemispheres, each composed of an external layer of grey matter surrounding white fibrous substances with a middle lobe situated between them and known as the *vermis*. The grey

matter is thrown into laminæ, separated by curved furrows or salci, and the *pia mater* dips into these fissures. In the interior are found masses of grey matter, especially one in each hemisphere, the **dentate** nucleus. It is from this nucleus that impulses are sent to the opposite cerebral cortex.

The chief **function of the cerebellum** appears to be the co-ordination of all muscular movement and posture, especially the maintenance of the equilibrium of the body. It is the organ by which the mind gains a knowledge of the conditions and positions of the muscles, which is absolutely essential to their harmonious action, especially in such complicated movements as walking and running. When the cerebellum of an animal is injured it can move any voluntary muscle at will, but it cannot walk or fly, nor can it balance its own body, since the muscles do not act with any co-ordination, *i.e.* a condition known as ataxia is produced.

There is, however, a gradual process of recovery due to re-education of the motor area of the cerebrum.

Thus, voluntary movements do not originate in the cerebellum, but only the power of co-ordinating these movements. An animal

retains sensation when its cerebellum is injured, and injury to this portion of the brain causes no pain. If one-half of the cerebellum is removed and time is allowed for the effect of the operation to pass off, it is found that the animal shows a weakness of the muscles of that side (*asthenia*), loss of muscular tone (*atonia*), *i.e.* the muscles are flabby, the movements are clumsy (*ataxia*), the effort used is not suitably graded (*dysmetria*), there is no proper co-ordination between opposing muscles (*asynergia*), and there is also a condition of tremor (*astasia*), on attempting voluntary movements.

3. **THE MID BRAIN** consists of the cerebral peduncles,

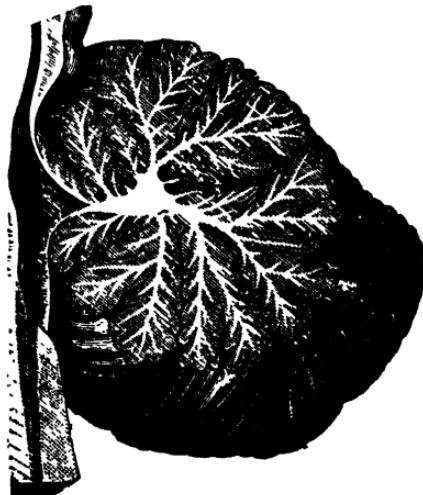


Fig. 144.—Section through the Cerebellum.

Showing the peculiar arrangement of the white and grey matter, forming what is known as the *arbor vitae* (tree of life).

or crura, which unite the pons and thalamus. Some of the fibres contained in it are motor (cortex to cord), while others unite the frontal and parietal lobes to the pons. It also contains three masses of nerve cells. One is the **red nucleus**, which is concerned in the maintenance of normal posture and muscle tone, another, the **superior corpora quadrigemina**, concerned with visual reflexes, and the third the **inferior corpora quadrigemina** which have to do with hearing.

4. **THE PONS** is continuous with the medulla oblongata below, and from its upper surface emerge the cerebral peduncles. Anteriorly it consists of a set of transverse fibres connecting the cerebellum of each side. Other fibres run from the cerebrum up and down the cord through the pons. There are also present, as detached masses of grey matter, the nuclei of origin of the fifth to the eighth cranial nerves (inclusive).

5. **THE MEDULLA OBLONGATA** is a mass of white and grey matter which connects the pons varolii with the spinal cord or *medulla spinalis*. It is about an inch in length, and is broader above, where it is continuous with the pons. Its grey matter, which is somewhat differently arranged from that in the spinal cord, occupies the interior. The central canal of the spinal cord runs into its lower half and then opens out into a cavity known as the **fourth ventricle**. This cavity is filled with cerebro-spinal fluid and opens at its upper end into the aqueduct of Sylvius, which again leads to the third ventricle.

We have noticed that the functions of the cerebrum and the cerebellum are not of vital importance, so that death does not instantly follow the removal or destruction of these parts of the brain. But the **functions of the medulla oblongata** are of such a nature that instant death is the result of its destruction. It governs those involuntary movements which constitute the acts of breathing and heart beat. The centres for the government of these acts are found in the floor of the fourth ventricle. Here are centres for respiration, regulation of the calibre of the smaller arteries (the vaso motor centre), for vomiting, and for the regulation of the rate of heart beat (cardio motor centre). In this region is also a centre for the regulation of the sweat and respiration. When it is destroyed the breathing instantly ceases. It is the only means of communication between the brain and the cord, and is therefore important as a conducting medium. It also possesses properties similar to those of the spinal cord. The medulla oblongata contains the nuclei of origin of the ninth to the twelfth cranial nerves.

THE CRANIAL NERVES.—From the under surface of the brain twelve pairs of nerves are given off. These are called the **cranial nerves**, and are numbered from before backwards, according to their *superficial* origins. They mainly supply the head and neck.

The first pair are the **olfactory nerves** or the nerves of smell. These are the *sensory* or *afferent* nerves, the fibres of which come from the mucous lining of the upper portion (*meatus*) of the nose. They then go through the many foramina in the ethmoid bone to the cortical centre in the hippocampal gyrus, a part of the temporal lobe. These nerves are amylinated.



Fig. 145.—The Under Surface of the Brain, showing the Origins of the Twelve Pairs of Cranial Nerves.

A, cerebrum; B, cerebellum; C, medulla oblongata; D, pons Varolii. The Roman numerals distinguish the cranial nerves (I to XII).

The second pair are the *sensory* nerves of the eye—the **optic nerves**, or nerves of sight. They originate in the retina and run to the occipital portion of the cerebrum, where the nerve impulses are converted to consciousness.

The third pair are purely motor and called the **motores oculi** (movers of the eyes). They are distributed to four of the muscles which move the eyeballs. They also supply the sphincter muscle of the iris, the ciliary muscle and the muscle of the upper eyelid, known as the levator palpebrae superioris (Lat. *palpebra*, the eyelid). Hence they are also concerned with the mechanism of accommodation. As with the fourth cranial nerve, their nuclei of origin lie in the floor of the aqueduct of Sylvius.

The fourth pair are *motor* nerves. Each is known as the Trochlear nerve. They supply one of the muscles of the eyes (the superior oblique, which turns the eye down and out), and are the smallest cranial nerves.

The nuclei of origin lie in the grey matter of the floor of the aqueduct of Sylvius. After leaving the nucleus the fibres **cross** over to the **opposite** side, and ends in the superior oblique muscle of the opposite eyeball. This crossing over of fibres from one side to the opposite only occurs with this nerve and a few fibres of the optic nerve.

The **fifth pair** are the largest nerves, containing both *motor* and *sensory* fibres. Each divides into three branches, and they are consequently called



Fig. 146.—The Cranial Nerves of the Left Side.

the trigeminal nerves. These three divisions are : Ophthalmic (sensory); maxillary (sensory); and mandibular (sensory and motor).

They supply the skin of the face, the lacrimal gland, the muscles, teeth and gums of both jaws, and sensation for the anterior two-thirds of the tongue. The jaw muscles here mentioned are those of mastication.

The **sixth pair** are supplied to the muscles which turn the eyeballs outwards. Hence the name **abducens nerve**. They are purely motor. Thus the muscles of the eye receive fibres from three distinct pairs of nerves—the third, fourth and sixth. Relatively to the small muscles they control, these nerves are of great size—showing how finely graded are the corresponding movements of the muscles.

The **seventh pair** are mixed, and called the **facial nerves**, since they supply fibres to the muscles of the face—the muscles of expression, not those of mastication. Also they supply the *taste* fibres for the anterior two-thirds of the tongue, *via* a special branch known as the *chorda tympani*.

The **eighth pair** are the **auditory nerves**—the *sensory* nerves which come from the ear. Strictly speaking, this nerve consists of two sets of fibres which go to quite different parts of the brain. One set is known as the *vestibular* fibres. They proceed from the semicircular canals, saccule and utricle, and are concerned with the control of muscular movement, especially in relation to the equilibrium and maintenance of the normal attitude of the body. The other set is known as the *cochlear* (Gr. *kochlos*, a shell fish) fibres, because they come from the spinal ganglion of the cochlea and are entirely concerned with hearing. The fibres ultimately lead to the temporal lobe (superior temporal gyrus) where the nervous impulses are translated into the consciousness of hearing.

The **ninth pair** are *mixed* and are called the **glossopharyngeal** (Gr. *glossa*, the tongue; and *pharynx*), because of their distribution to these organs. Their *sensory* fibres proceed from the posterior third of the tongue, for taste and sensation, and go to the sensory nucleus in the medulla. From these fresh relays proceed to the sensory cortex of the cerebrum, there to be translated into consciousness. The *motor* fibres come from the medulla, and supply the muscles of the pharynx.

The **tenth pair** are termed the **vagi** (Lat. *vagus*, wandering) or **pneumogastric nerves** (Gr. *pnumon*, the lung; and *gaster*, stomach). They are *mixed* nerves whose fibres are concerned with the larynx, lungs, heart, intestines, stomach and the liver. This nerve has a more extensive distribution than any other cranial nerve, hence its name.

The **eleventh pair**, known as the **spinal accessory**, are exclusively *motor* nerves which supply two muscles of the neck, the sternomastoid and trapezius. This nerve is so called because it consists of two parts. One arises from the medulla and is **accessory** to the vagus, while the other arises from the anterior horns of the upper cervical region of the spinal cord. This is, therefore, the **spinal** portion.

The **twelfth pair** or **hypoglossal** are purely *motor* nerves which supply fibres to the muscles of the tongue, intrinsic and extrinsic. The nucleus of origin lies in the medulla oblongata, near the fourth ventricle.

THE CRANIAL NERVES.

Pair	Name	Distribution	Function
I	Olfactory	Superior meatus of nose	Smell.
II	Optic	Retina (rods and cones)	Sight.
III	Motores oculi	{ Ciliary M., sphincter iridis The 4 recti, inferior oblique	Accommodation. Eye movements.
IV	Trochlear	Superior oblique	Eyedown and out.
V	Trigeminal	{ Teeth, skin of face and head Muscles of mastication	Sensation. Movement.
VI	Abducens	External rectus	Eye turned out.
VII	Facial	{ Muscles of facial expression Taste to anterior two-thirds of the tongue	Motor. Sensory.

THE CRANIAL NERVES—continued.

Pair	Name	Distribution	Function
VIII	Auditory	a. Vestibular portion — to semicircular canals and the vestibule b. Cochlear portion Taste posterior 2/3 tongue	Posture. Equilibrium. Hearing. Sensory.
IX	Glossopharyngeal	Motor to pharyngeal muscles	Motor.
X	Vagus	Larynx, lungs, heart, stomach, gut, liver, pancreas, spleen	Secretory. Motor. Sensory.
XI	Spinal accessory	Sternomastoid, trapezius	Motor
XII	Hypoglossal	Muscles of tongue	Motor

SUMMARY**COVERINGS OF THE BRAIN**—for protection and nutrition

1. **Pia mater**—innermost, vascular, closely invests brain.
2. **Arachnoid mater**—thin, fibrous; between it and pia is C.S.F.
3. **Dura mater**—tough, protects brain, also serves as periosteum.

CEREBRUM—seat of intelligence, will, memory, inhibition, thought.

R. and L. hemispheres (5-lobed), convoluted surface (sulci, gyri).
Grey matter (nerve cells) forms cortex and basal ganglia.
Two cavities (ventricles—filled with C.S.F.), one in each hemisphere.

CEREBELLUM—regulates posture and equilibration.

R. and L. hemispheres + connecting central part (vermis).
Fills occipital part cranial cavity. Is very folded.
Three peduncles—to connect with rest of C.N.S.
Grey matter outside, detached masses (dentate nuclei) inside.

MID BRAIN—consists of several parts : -

The Crura—bundles of fibres uniting pons and thalamus.
Sylvian aqueduct, substantia nigra (pigmented nerve cells).
Red nucleus (rubro spinal tract), pyramidal fibres.
Two sup. corp. quad. (visual reflexes), two inf. corp. quad. (hearing).

PONS—conducting medium between cerebrum, cerebellum, medulla.

Scattered grey masses—nuclei of V, VI, VII, VIII cranial nerves.

MEDULLA OBLONGATA—conducts impulses between brain and cord.

Nuclei of IX, X, XI, XII in floor of fourth ventricle.

Pyramids, olivary bodies, restiform bodies (inf. cerebellar peduncle).
Centres for respiration, heart beat, calibre of arterioles, vomiting and deglutition.

CHAPTER XXXII

THE SPINAL CORD (*MEDULLA SPINALIS*)

THE SPINAL CORD is the long cylinder of nerve matter contained in the *spinal cavity* formed by the *vertebral column*. It extends from the *medulla oblongata*, i.e. at the level of the upper border of the atlas, to the lower border of the *first lumbar vertebra*, and measures about 18 inches in length. It is nearly as thick as the little finger. Above, it is continuous with the brain, while below it ends in a pointed extremity known as the *conus medullaris*.

COVERINGS.—Like the brain, the spinal cord is closely invested by the **pia mater** from which it receives its blood supply. Over this lies the serous **arachnoid membrane**, and exterior to the arachnoid is a continuation of the inner layer of the **dura mater** of the brain.

The **arachnoid membrane** of the cord, unlike that of the brain, is not in contact with the **pia mater**, but forms a loose bag around it. The **dura mater**, also, does not lie close against the vertebrae as it does against the cranium, but is separated from them by a layer of loose areolar tissue which forms a soft protecting covering, enabling the back to bend without injury to the cord.

LUMBAR PUNCTURE.—As the **dura mater** ends at the lower border of the second sacral vertebra (S₂), and the spinal cord at the lower border of the first lumbar vertebra (L₂), it is therefore possible to puncture the subarachnoid space anywhere between these limits with a needle without any risk of injury to the cord. This is usually done between the spines of L₄ and L₅. Fluid may be withdrawn, for diagnostic examination (in syphilis, tubercular meningitis, encephalitis lethargica, and acute anterior polio-myelitis), to introduce drugs (for spinal anaesthesia), curative sera or lipiodol (X-ray examination for tumours), or to relieve intracranial pressure (in uræmia, meningitis).

STRUCTURE OF THE CORD.—On making a transverse section of the spinal cord we notice that the grey nerve substance is in the interior, and is surrounded by white matter. The cord is divided into right and left parts by two deep depressions or **fissures**. The front or **anterior fissure** is wider than the other, but not so deep. The **posterior fissure** is not a true fissure, but simply a layer of thin connective tissue, penetrating almost to the centre. In the centre of the cord is a very small, almost microscopic, canal—the **central canal**—which is

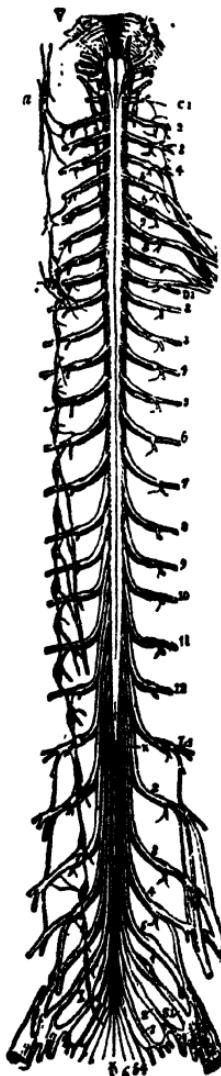


Fig. 148.—Transverse Section of the Spinal Cord.

a, anterior fissure; p, posterior fissure; c, grey matter; pn, posterior nerve-root; ac, anterior cornu or horn of grey matter; pc, posterior cornu.

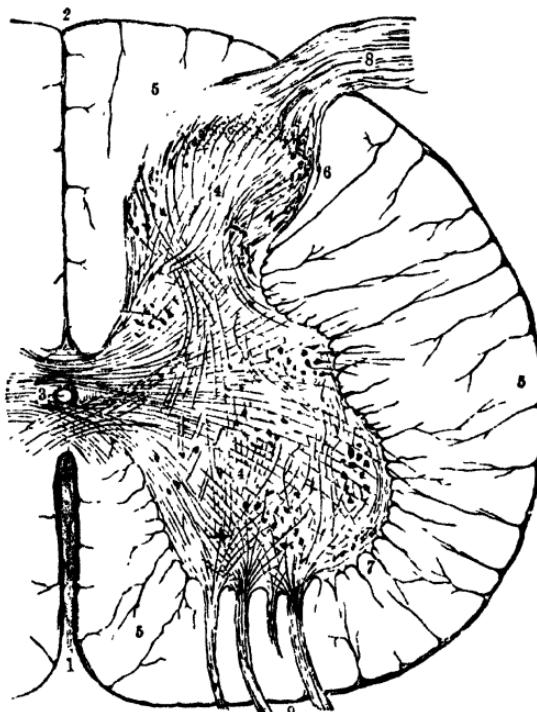
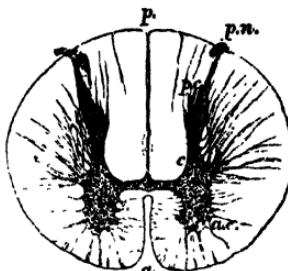


Fig. 149.—Transverse Section of half the Spinal Cord. ($\times 8$)

1, anterior fissure; 2, posterior fissure; 3, central canal; 4, grey matter; 5, white matter; 6, posterior cornu; 7, anterior cornu; 8, posterior nerve-root; 9, anterior nerve-root.

Fig. 147.—The Spinal Cord and its Nerves (the Spinal Nerves), together with the Sympathetic Chain on one side.

v, pons Varolii, below which is the medulla oblongata; c 1 to 8, the cervical nerves; p 1 to 12, the dorsal nerves; l 1 to 5, the lumbar nerves; s 1 to 5, the sacral nerves; 6, the coccygeal nerve; X, the terminal fibre of the cord; a to 1, the sympathetic chain, showing the connection with the spinal nerves.

filled with cerebro-spinal fluid, and lined with columnar ciliated epithelium. The white matter is composed of columns of fibres, called *tracts*, running to and from *the brain*.

Large nerves are given off from the spinal cord, right and left, symmetrically throughout its whole length, termed **spinal nerves**. In the cervical and dorsal regions they emerge in pairs, passing out on each side through openings between the vertebrae. There are thirty-one pairs of these nerves. At the lower end of the cord the lumbar and sacral nerves come off crowded together in the form of a parallel bundle which is called the **cauda equina**, from its resemblance to a horse's tail.

The **grey matter** of the spinal cord projects backward and forward on each side, forming the posterior and anterior cornua or horns (*I. at. cornu*, a horn). This grey matter is in the shape of the letter H, the upper ends of the letter forming the anterior horn and the lower ends the posterior horn. In the centre of the connecting bar of this letter, runs the central canal of the spinal cord. Into the posterior cornu a bundle of fibres pass, forming the **posterior, dorsal or afferent root** of a spinal nerve. Fibres also pass outward from the anterior cornu, giving rise to an **anterior, ventral or efferent root**. These two roots unite to form a **spinal nerve trunk**. The nerve trunks are thus formed by the union of anterior and posterior roots ; and after division and subdivision they supply fibres to the skin and the voluntary muscles.

Each of the posterior roots has on it a swelling which consists of a collection of nerve cells known as a **ganglion**. They are placed in the intervertebral foramina. Each of the cells in the ganglia has a process which at once divides into two portions. One runs into the spinal cord constituting the posterior root, and the other runs to the periphery in the spinal nerve.

THE FUNCTIONS OF THE ROOTS OF THE SPINAL NERVES have been ascertained by the following observations : 1. If the **anterior roots** of the spinal nerves supplying a certain limb (or group of muscles) are cut, the power of voluntary movement in that limb will be destroyed, and the limb will hang in a flaccid paralysed condition, with loss of tone and temporary vaso-dilation, though sensation will remain unimpaired. If one of the roots is cut, then any stimulus applied to that portion which remains in contact with the cord, known as the "central" end, will cause no sensation, nor will there be any movement of the limb in question. But if the other portion of the divided root be irritated, *i.e.* the peripheral or distal end,

the muscles of the limb will contract. Thus we learn that the anterior roots consist of efferent or motor fibres.

2. If the posterior root of the nerve supplying a certain part is similarly injured, the animal will still have control over the voluntary muscles of that part with inco-ordinated muscular movements and loss of tone, but the part will have lost all power of sensation. Again, if the root is divided, any irritation applied to the portion in contact with the cord will cause more

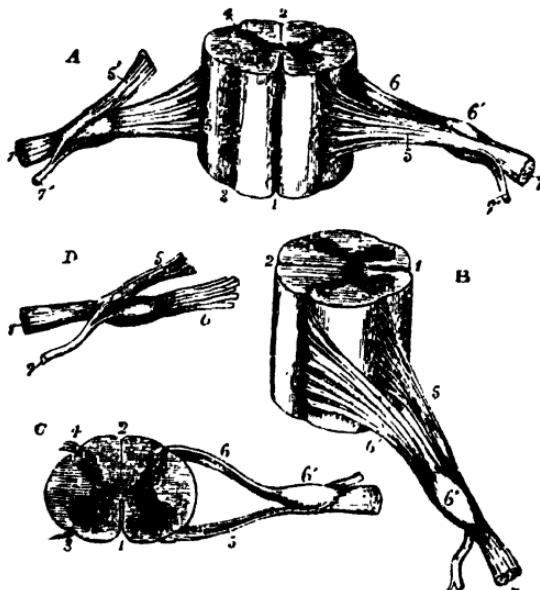


Fig. 150.—Roots of a Spinal Nerve issuing from the Cord.

A, from before; B, from the right side; C, from above; D, the roots separated. 1, anterior fissure; 2, posterior fissure; 3 and 4, lateral grooves of the cord; 5, anterior root; 6, posterior root; 6', posterior ganglion; 7, the united or compound nerve; 7', the posterior branch. In A one anterior root is divided and turned upwards.

or less pain; but no effect is produced by the irritation of the other part. **The posterior roots consist mainly of sensory or afferent fibres.**

Similar observations teach us that the **spinal nerves**, formed by the union of the anterior and posterior roots, are mixed nerves, that is, nerves composed of both **sensory and motor fibres**. For, if the spinal nerve supplying a certain part of the body is injured to such an extent that its fibres are severed, both **sensation and voluntary movement are lost to that part.**

Further, any irritation received by that portion of the nerve still in communication with the cord will produce sensation; while irritation to the cut portion will cause muscular contraction.

REFERRED PAINS.—It is an interesting fact that, when the portion of a divided spinal nerve which remains in communication with the brain is irritated, or, when the corresponding portion of a divided sensory root is irritated, the sensation is not felt at the point where the irritation is applied, but is always referred to the part in which the fibres of the divided nerve or root *originate*. Thus, if any stimulus be applied to the spinal portions of the nerves which supply the arm (supposing those nerves to have been severed), yet the sensations will be felt in the fingers and in the skin of the arm, even though communication with the brain—the seat of all sensation—is cut off; and even in the case of an amputated limb, the sensation will still be referred to the lost part by the brain. Such sensations are known as “referred pains.” They are of great value to a physician in the diagnosis of disease. This will enable us to explain the cause of the sensation called “pins and needles” produced by pressure on a nerve at the elbow. The irritation is transmitted direct to the brain by one or more sensory nerves, and the brain simply refers the sensation to the extremities of the irritated nerve. Stimuli applied to the viscera often provoke painful sensations. But the pain is referred to some cutaneous surface, and not to the viscus in which it arises. To each organ there is a definite and constant area to which sensation is referred. In many cases the area is even hyper-aesthetic, i.e. exquisitely tender. Possibly it may be that the posterior root ganglion which receives fibres from the viscus is the connecting link.

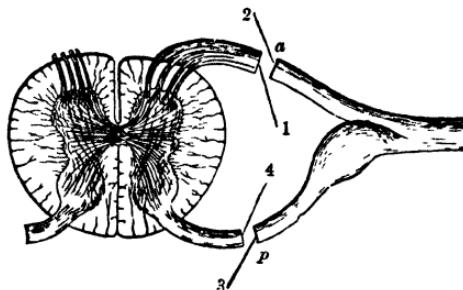


Fig. 151.—Illustrating the Functions of the Roots of the Spinal Nerves.

a, anterior root. *1*, posterior root.
Divided at a.—Stimulated at *1*: no result. Stimulated at *2*: contraction of muscles supplied with fibres from the root.
Divided at p.—Stimulated at *3*: no result. Stimulated at *4*: pain produced.

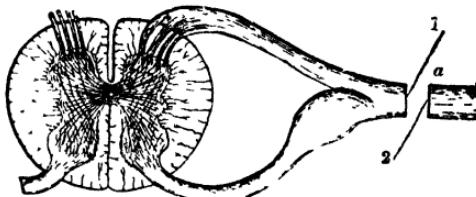


Fig. 152.—Illustrating the Functions of the Spinal Nerves.

Divided at a.—Stimulated at *1*: pain. Stimulated at *2*: muscular contraction.

FUNCTIONS OF THE SPINAL CORD.—We may now study the functions of the spinal cord. When the spinal

cord is cut through or injured at any point, all power of voluntary movement and all sensation is lost to every part of the body, supplied with fibres from nerves which originate below that point. That is, we have a condition of complete anaesthesia and paralysis of the parts supplied. Therefore the cord is a medium by which motor and sensory impressions are conducted to and from the brain. If we now pinch or otherwise irritate the limbs which are thus cut off from the brain, they are suddenly drawn up by the contraction of their muscles, and this entirely without any exercise of the will. Such an action is termed a **reflex action**. It consists of a stimulation of the sensory fibres of

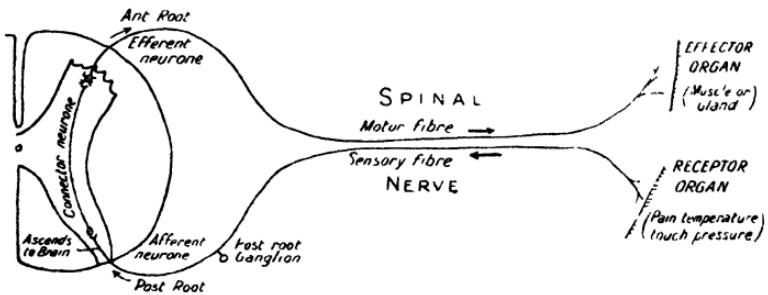


Fig. 153.—Diagram of a Spinal Nerve and its Roots.

Note that in an ordinary spinal reflex three neurones are involved—the cell in the posterior root ganglion, the connector cell in the posterior horn, and the effector cell in the anterior horn, each with its processes (dendrites and axon).

a **receptor organ** which is conducted by a sensory nerve to a nerve centre, and a reflection of this disturbance from the nerve centre through one or more motor nerves to an **effector organ**, causing a contraction of the muscles or a secretion of the gland in which the motor fibres terminate. In any reflex path certain parts can be made out: there is a **receptor organ** situated peripherally, e.g. the retina capable of being stimulated. A sensory nerve runs from it to a nerve centre, from which by its dendritic relations to other nerve cells fresh axons run to an **effector organ**—a muscle or a gland. It will thus be seen that the spinal cord is not merely a *conductor* of impulses, but that it is a **centre for reflex actions**. This power is possessed by the grey matter of the cord only, the white substance being only a conductor of impulses, *via* the tracts already mentioned.

REFLEX ACTIONS OF THE SPINAL CORD:—

1. Centres for micturition, defaecation and parturition—in the grey matter of the lumbar enlargement of the cord,

2. Centres for muscle tone, *i.e.* to keep the muscles in a condition of partial contraction, ready for any eventuality.

3. Subsidiary vaso-motor centres in the grey matter of the dorsal region of the cord, and subsidiary sweat centres.

These latter are controlled by the chief ones in the medulla.

Characteristics of Reflex Actions.—These may briefly be summed up as :—Stimulation of the same locality always produces the same reflex, and all reflexes take time. No nerve impulse can pass backwards, traffic is always “one way.” Reflexes can be fatigued, the seat of the fatigue being in the grey matter of the cord. The repeated passage of a (non-fatiguing) stimulus has the effect of enabling the reflex to be more easily produced. This is known as “facilitation” and is the basis of memory. Lastly, all reflexes are purposive, and fatal, in the sense that once the stimulus has started, the reflex follows inevitably whether for good or ill.

Hundreds of **reflex actions** are going on continually in our bodies without our knowledge, and among them we include the so-called *vital functions* of the important organs, the cessation of which would cause instant death. Thus, the **action of the respiratory muscles** is the ultimate result of a reflex action. In this case the irritation of the sensory nerves concerned is due to the imperfectly aërated condition of the blood. Strictly one would say the respiratory centre exhibits a specific irritability for carbon dioxide, *i.e.* it is very sensitive to variations in the amount of this gas present in the blood. The stimulus thus made is conveyed from the *medulla oblongata*, down the spinal cord and through motor nerves which govern the intercostal muscles, and the diaphragm. Even walking, reading and other familiar actions of voluntary muscles are reflex movements. Of course, such movements are sometimes purely voluntary, especially in childhood, but in time the nerve centres become so used to arranging a certain succession of movements that they act in their accustomed manner without the control of the will. We may walk without knowing that we are walking, or, at least, we should say it is done subconsciously.

The spinal cord differs in shape and cross section at different levels. Thus it has two enlargements, one cervical and one lumbar—due to the increased number of nerves leaving the cord in those regions to supply the upper and lower limbs respectively. Also it is found there is much more white matter towards the cephalic end. This is clearly due to the fact that since the white matter is a collection of nerve fibres acting as

conductors (both up and down) there must be more of them passing through the cervical region than elsewhere.

It appears that consciousness tends to prevent or reduce the number of reflex movements. Thus, the tickling of the feet during sleep will cause muscular contraction more readily than when we are awake. And again, the unexpected motion of an object near the eyes causes the eyelids to close instantly; whereas, had we been prepared for it, we should probably have been able to keep the eyes open.

It has been ascertained that the majority of the motor fibres, which originate in the cortex, pass down to the front of the medulla, and then cross over, and descend in the cord on the opposite side, while the remaining fibres descend the cord on the same side. Hence, if one lateral half of the cord is injured, the power of voluntary movement will be almost entirely lost on the same side of the body, below the seat of the injury, but will be practically unimpaired on the opposite side. The sensory fibres, on entering the cord, pass chiefly up the same side to the medulla, and then cross over to the other side of the brain, while some cross to the opposite side immediately on entering the cord. Hence there will be some loss of pain and temperature on the opposite side. Touch is retained, though it is impaired. On the opposite side there will be loss of sense of position and of localisation of touch.

A lesion of the dorsal region of the cord involving only one-half of it (*i.e.* unilateral) is known as a "Brown-Séquard paralysis," since he first described them. It has the following characteristics: motor paralysis and slight vaso-motor paralysis of the same side, loss of pain, heat and cold on the opposite side, while touch is retained on both sides. If the cord were completely cut across there would be complete paralysis and loss of sensation on both sides of the parts below the lesion, but the functions of the bladder and rectum would be unimpaired, though all voluntary control over them would be lost for ever. All this is preceded by a condition of "spinal shock"—a temporary state of loss of muscle tone, and a fall in blood pressure. Its degree and duration depend on the complexity of the nervous system of the animal so affected. Ultimately it passes off, so that tone, reflexes and raised blood pressure reappear. If the section were in the cervical region there would be a constricted pupil since the dilator fibres would be paralysed, while if the lesion is above the point of exit of the phrenic nerves which control the diaphragm, then death would occur at once through paralysis of the diaphragm. In judicial "death by hanging," the cord is broken in the region of the first and second cervical vertebrae, causing instantaneous death.

SUMMARY

THE SPINAL CORD

Position . . .	In spinal canal of the vertebral column. About 18 inches long, $\frac{1}{4}$ inch thick. From medulla oblongata to lower border of L.I.
Coats . . .	<i>Pia mater</i> —delicate, vascular. <i>Arachnoid</i> —serous, forming a loose bag. <i>Dura mater</i> —tough, fibrous.

Structure .	{	<i>Grey matter</i> internal—shape of letter H. Mostly nerve cells and neuroglia. <i>White matter</i> external—nerve fibres only. <i>Anterior fissure</i> —wide and shallow. <i>Posterior fissure</i> —deep and narrow. <i>Central canal</i> —in the grey commissure.
Nerves	{	Thirty-one pairs—between the vertebrae. Crowded at lower extremity of cord— <i>cauda equina</i> . Each trunk formed by union of two roots. Roots { Anterior—motor (efferent)—movement. Posterior—sensory (afferent)—sensation.
Functions	{	Conducts impulses—to and from brain. Centre for reflexes—defaecation, micturition, parturition, limb movements. <i>Sensory fibres</i> —carry impulses to the brain from stimulated receptor organs. Some cross as they enter the cord, others do so higher up. <i>Motor fibres</i> —convey impulses to muscle or glands. Mostly cross in the medulla oblongata; a few cross in the cord.

REFLEX ACTION—involuntary motor response to sensory stimulus.

Its components are :—

- A receptor organ—to receive the appropriate stimuli, and convert them into nervous impulses.
- Afferent fibres—to carry the impulses to a centre.
- A centre—to receive and transmit the impulses.
- Efferent fibres—to carry the impulses to an end organ.
- An effector organ—to convert the impulses into muscular or glandular action.

CHAPTER XXXIII

SENSATION—CUTANEOUS SENSATIONS

THE nervous system is the medium by which we derive a very limited and wholly incomplete knowledge of the existence of the various parts of the body, and of the external world. This knowledge is based upon **sensations**, so presumably if we were incapable of receiving or perceiving sensations we should be devoid of all consciousness. The latter may be defined as the sum total of all the stimuli we are receiving at any particular moment. Loss of consciousness occurs naturally during sleep, and artificially during general anaesthesia.

REQUISITES FOR THE PRODUCTION OF SENSATION.—In order to produce a sensation of any kind, three anatomical parts are necessary. These are :—

1. The provision of suitable **receiving apparatus** (or receptor organs), each being specially adapted for the absorption of some particular sort of energy—ether waves (light and heat), sound waves, pressure. This absorbed energy is then converted into nervous impulses.
2. **Nerve fibres**, which carry these impulses to the brain.
3. The **brain (cerebral cortex)**, which translates these impulses into what we call consciousness.

Concerning these conditions we make certain remarks :—

(1) The stimulus or energy which the receptor organ absorbs must be of its own peculiar kind, *i.e.* it must be the appropriate one. Thus in order to *see* naturally we require ether waves, and these must be between certain limits of frequency.

It may be argued, however, that one can see “stars” by a blow on the eye, but this is not the usual way of viewing the celestial bodies. It is much more comfortable and natural to use a telescope. In some mental conditions (*e.g.* migraine) one sees flashes of light and plays of colour which have no external origin. Both these ways are unnatural, and it is only when the applied stimulus is the appropriate one that we see in the proper sense of the word. Moreover, the receptor organs are

far more sensitive to their natural stimuli than to any other.

(2) It is thought that all sensory fibres carry the *same* sort of impulse, but the sensation evoked depends entirely on the precise portion of the cerebral cortex to which the impulse eventually is carried.

(3) The analysis of the sensation is carried out by peripheral structures.

CLASSIFICATION OF SENSATIONS:—

i. According to their precision of definition, or the sharpness of their tuning.

(a) **Special sensations**—arising from such receptor organs as are adapted for sight, hearing, smell, taste, pain, temperature and touch. These give no information concerning our environment both in respect of its nature, degree and localisation.

Eye—light, colour, shape, distance—**sight**.

Ear—pitch, intensity, quality, position—**sound**.

Skin—touch, pain, heat, cold—**feelings**.

Tongue—acid, sweet, bitter, salt—**taste**.

Nose—pungent, pleasant, putrid—**smell**.

(b) **General sensations.** These rarely reach the level of consciousness, and even if they do they are usually of a vague, ill-defined and generalised character, such as hunger, thirst, fatigue, muscle and joint sense. There is a tendency to spread, and the tuning is far from sharp.

Although some of these sensations are at times more or less localised, yet, at the same time, they are accompanied by a general sensation. For instance, during hunger a distinct pain is felt in the region of the stomach, while there is also a feeling of general discomfort.

One of the common sensations is that which has been termed the “**muscular sense**.” It is that sensation by which we become acquainted with the condition of the muscles. Although the mind may be unconscious of the existence of the muscles of any particular part, yet it is made aware of their condition, and is able to regulate their contraction with extreme precision. Thus, when walking on a windy day, we incline our bodies in proportion to the force of the wind. By means of this sense we may perform such complicated acts as writing or pianoforte-playing without the aid of sight. It is the muscular sense which enables us to estimate the weight of a body by the effort required to lift it. We are most conscious of this muscular sensation when we make the muscles rigid by a voluntary effort.

2. Sensations may also be classified as *objective* and *subjective*.
 (a) **Objective sensations** are produced by external causes or conditions. These are studied in physiology as being the natural way in which we are brought into conscious relation with our environment.

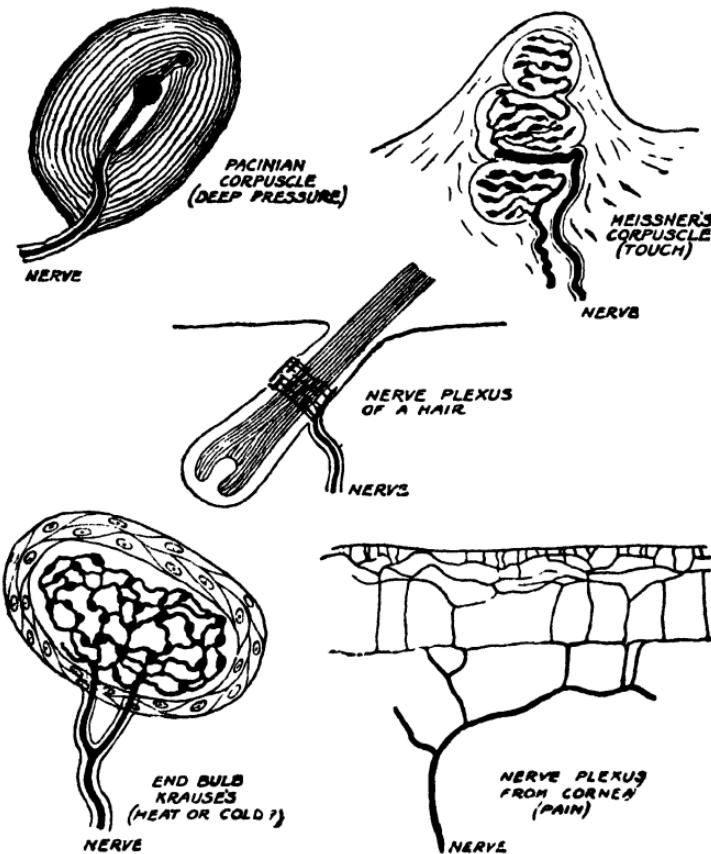


Fig. 154.—Receptor Organs in the Skin—Deep Pressure, Touch, Heat, Cold and Pain.

(b) **Subjective sensations** are those in which the exciting cause is a peculiar condition of the cerebrum itself. They have no origin external to the body, e.g. noises in the ears, flashes of light before the eyes (in migraine and eclampsia), the "lightning pains" in tabes, the "aura" preceding an epileptic fit, the various sensations suggested to one who is hypnotised, or

that we imagine when dreaming. The mind generally refers such sensations to external objects, and hence arise **illusions**. They sometimes form part of a diseased condition, and are therefore of use in diagnosis. Similarly, the fusion of a series of intermittent stimuli into a continuous sensation (*e.g.* a catherine wheel) is a subjective sensation.

The sense of touch may be regarded as a modification of common sensation ; and all parts of the body which are supplied with sensory nerves are to a certain extent **organs of touch** ; but this sense is perfected only in the *skin, tongue and lips*. It should be noted, however, that the sensation of "touch" is really a complex one. It can be divided into those of *pain, cold, heat, and touch or pressure*.

Pain has many curious psychological characters. Thus it can be referred to a lost limb, to a part of the body in which it does not originate, and to accompany some bodily movement originally objective, but now completely healed.

The **sensitivity of the skin** is due to the presence of nerve fibres distributed through the dermis. Some of these nerve filaments subdivide in the skin, and possibly terminate in individual cells ; but many of them, especially in the more sensitive parts of the skin, end in minute bodies of various forms. They are to be regarded as receptor organs, each responding to its appropriate stimulus. If one examines carefully any area of skin it will be found that the appreciation of pain, temperature and touch is confined to certain spots separated by non-responsive intervals, *i.e.* they have a punctiform distribution. For instance, there are spots for pain, for cold, for heat and for touch. Stimulation of a small isolated area does not give a mixture of *all* the sensations, but just *one*. No doubt each area contains a special sensory end organ. These areas are irregular in shape and distribution, sometimes separated and sometimes overlapping. But it is to be noted that a cold spot, for instance, is always a cold spot, even if touched with a hot object. Of course this only bears out Müller's law mentioned above, *i.e.* the sensation produced depends on the



Fig. 155.—**A Nerve of the Finger, with Pacinian Bodies attached.**
Natural size.

end organ stimulated, and not on its mode of stimulation. Menthol rubbed on the skin only stimulates the cold spots. The distribution of these spots is not uniform.

Touch spots are of different varieties. The largest of these are oval bodies having a diameter of from $\frac{1}{8}$ to $\frac{1}{16}$ of an inch. They are called **Pacinian bodies**, after Pacini, their discoverer, and are abundantly distributed in the skin of the palms and soles, and in tendons and joints. They are situated on the cutaneous nerves. Other smaller bodies, called **tactile corpuscles** of Meissner, are abundant in the papillæ of the cutis vera of the fingers and toes, lips and tip of tongue. They are very numerous around the hair follicles, especially the whiskers of carnivora. **Krause's end bulbs** are other oval bodies found in the conjunctiva of the eye, the lips, in tendons, and in the genital organs. Touch is really due to a deformation of the skin. In some way the energy of pressure is converted into a nerve impulse.

In all these cases the appropriate or "effective" stimulus is pressure, leading to a deformation. Uniform and generalised alteration of pressure (as on a high mountain top or down a mine) produces no tactile effect.

In the most sensitive parts of the skin papillæ are very abundant, and the epidermis lying over them is thin. Many of the papillæ are also supplied with touch corpuscles. In other parts, as in the heel, the outer skin is so thick that the sense of touch is dulled.

The degree of sensitivity of the skin may be measured by the power of distinguishing between two or more sensations produced at points very near each other. For instance, open a pair of compasses till the points are about 1 inch apart. Apply these points to the palm of the hand, and two distinct sensations are produced. Now apply the points to the skin of the arm, and the sensation is such as would be produced by the application of a single point. Hence we say that the hand is more sensitive to touch than the arm.

There are also free nerve terminations to be found in the cornea and larynx especially, but also scattered about in all parts of the epidermis. On stimulation they can only evoke the sensation of pain.

The temperature spots are separate, that is, a cold spot is always a **cold spot** no matter how stimulated, even if by a **hot wire pencil**, and similarly with the **hot spots**. The precise end organs concerned are not known, nor their mode of action. The phenomenon of goose skin is as readily shown on entering a hot bath as a cold one.

SUMMARY

SENSATION—the translation into consciousness of a sensory nerve impulse arriving at the cerebral cortex. In all cases the detailed analysis is believed to be peripheral.

CLASSIFICATION.

1. **Objective or real** (physiological)—due to some external agency.
 - a. General—hunger, thirst, fatigue, muscle and joint sense.
 - b. Special—pain, touch, cold, heat, sight, hearing, taste.
2. **Subjective or imaginary** (psychological)—some internal agency.
Flashes of light (migraine) : noises in ear (overdose of quinine) ;
epileptic aura : hysterical blindness, vomiting, and anaesthesia.

ANATOMICAL COMPONENTS.

1. **Receiving apparatus** (receptor organs)—detectors and amplifiers.
Special “end organ,” each to absorb its appropriate energy,
which is converted to a “nerve impulse.”
2. **Conducting fibres**—carry these impulses to cerebral cortex.
3. **Cortical centre**—where impulse is translated into “consciousness.”

CUTANEOUS SENSATIONS

—punctate distribution, bizarre patterns.

1. **Touch**—corpuscles of Pacini, Meissner ; end bulbs, tactile corpuscles.
2. **Pain**—free nerve ends (skin, larynx, cornea).
3. **Heat** . } individual end organs not yet traced.
4. **Cold** . }

MUSCLE AND TENDON SENSATIONS

—for estimation of degree
of muscular contraction, maintenance of posture and equilibrium.
Muscle spindles (in muscles), organ of Golgi (in tendon).

CHAPTER XXXIV

THE TONGUE AND TASTE—THE NOSE AND SMELL

THE TONGUE is a muscular organ covered with mucous membrane and occupying the floor of the mouth. It is attached

by means of muscles to the lower jaw, and is also connected behind with the *hyoid bone*.

The **organs of taste** lie embedded in the mucous membrane of the tongue, especially that at the upper and back surface, and also in the mucous membrane of the posterior portion of the *palate*.

The tongue also helps in speech, mastication and deglutition. Some of the lingual muscles are extrinsic, having a partial attachment to adjacent bones (*hyoid* and *mandible*), while others are intrinsic with no external attachment. The intrinsic muscles are for alterations of shape, and the extrinsic muscles move it about. They are all supplied by the *twelfth cranial nerve*, the *hypoglossal*. Embedded in the muscle of the under



Fig. 156.—The Upper Surface of the Human Tongue.

Note the large circumvallate papillæ at the back of the tongue.

surface are numerous serous and mucous glands.

On the under surface of the tongue the **mucous membrane**

is smooth and thin, like that of the walls of the mouth generally ; but its upper surface is rendered rough and sensitive to taste by a number of **papillæ** which are richly supplied with nerve terminations. It is these which constitute the sensory or receptor organs for taste.

The lingual papillæ are large compared with ordinary dermal papillæ. They are of three varieties, which are also in distribution quite distinct from each other. (1) The most numerous of these are conical or cylindrical in shape, and are called **filiform** (Lat. *filum*, a thread). They are especially found over the anterior two-thirds of the tongue. (2) Mixed with these, but more particularly at the sides and tip, are a number of larger papillæ called **fungiform** (Lat. *fungus*, a mushroom) on account of their resemblance in form to certain of the fungi. They each consist of a round and broad extremity supported on a narrower stalk, and are easily distinguished from the others by their deep red colour. Many of them contain special structures known as taste buds (see Fig. 157). (3) At the back of the tongue there are from seven to twelve very large papillæ arranged in two rows obliquely, so as to form the letter V with the point turned backwards, i.e. towards the foramen cæcum. These are termed the **circumvallate papillæ** (Lat. *circum*, around ; and *vallum*, a rampart) because they are each surrounded by a kind of wall or rampart. In the epithelium forming the sides of the vallum are found taste buds.

TASTE BUDS form the receptor organ for taste. They are small oval bodies lying in the epithelium over the lingual papillæ. On microscopic examination each consists of an outer layer of cylindrical cells, which serve to hold up the central mass of taste cells proper. Each taste or **gustatory cell** has a small hairy projection to the mouth, which therefore comes into contact with the food being eaten. The other end of the cell is in relation to the nerves of taste—the **chorda tympani branch of the seventh (facial) nerve** for the anterior two-thirds

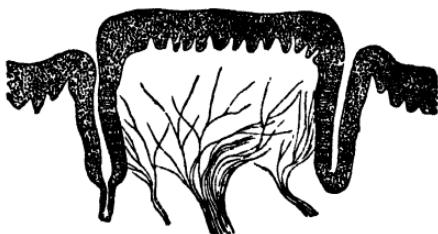


Fig. 157.—Section of a Circumvallate Papilla, showing the Distribution of its Nerve-fibres.

Note the taste buds lying in the walls of the papilla, with their associated nerve fibres.

of the tongue, and the glossopharyngeal for the posterior third.

It is easy to show that different portions of the mucous membrane of the tongue and palate possess different powers. Sweet and salt tastes are perceived more readily at the tip than at the back of the tongue. Sugar may be brought into contact with the back of the tongue or palate without any taste being detected, at least until the tongue and the palate have been pressed together. Bitter tastes are perceived best when applied to the back part of the tongue, and acids at the edge. It thus seems as if there were many different sets of end organs, each being stimulated in its own appropriate manner.

It appears that, in order to produce the sensation we call taste, the particles of the substance tasted must come in actual contact with the nerve-terminations of the mucous membrane ; that is, they must penetrate the outer layer of the membrane which covers the nerve-endings. Hence the substance to be tasted must either be in solution, or must be capable of being dissolved in the saliva or the mucus of the mouth, so that it may be easily absorbed. It is on this basis that it is supposed the appropriate or adequate stimulus for taste is a chemical one. Any attempt at correlating taste and chemical composition soon fails. We do not know what governs taste, or indeed why any substance should have a taste at all.

We must also remember that there is no sensation without the brain—that we do not taste a substance till the sensory receptor organs (taste buds) have been stimulated, and nerve impulses have been set up and transmitted to the brain (hippocampal gyrus). Here these impulses are converted into the sensation of taste, though how this comes about we have no idea. This is a psychological problem.

Many of the sensations which we call taste or flavour are not simple but very complex, in which both smell and touch play a very important part. Smell is so closely associated with the sense of taste that the odour of a substance frequently suggests the taste, and the taste sometimes suggests the odour. When the sense of smell is temporarily destroyed as, for instance, during a severe cold, taste is often partially or entirely lost until the sense of smell returns. This explains also the common practice of holding the nose while taking a dose of nauseous medicine.

THE NOSE contains the organ of smell. It consists of the external nose which is a projection from the centre of the face, and the nasal cavities situated one each side of the nasal septum. They open to the exterior by the anterior nares and to the nasal part of the pharynx by the posterior nares (*choanæ*).

The receptor cells lie in the mucous membrane over the surface of the ethmoid bone, this portion only of the nasal

cavities being supplied by filaments of the olfactory nerves. In this mucous membrane will be found specialised nerve epithelial cells—the receptor olfactory cells. Each cell has two processes—one projects as a fine hair-like process into the nasal cavity, and the other process ramifies with the fibres of the olfactory nerve, which convey the nerve impulse generated by the stimulus, to the brain.

During ordinary breathing through the nose, the air passes gently through the lower and wider portions of the nasal cavities, without disturbing to any great extent the air which is enclosed by the scroll-like folds of the turbinated bones. Consequently, even though the air may contain particles of odorous matter, few or none of them come into contact with the terminations of the olfactory nerve, and little or no sensation of smell is experienced. When we wish to perceive an odour more distinctly, we "sniff" the air. In doing this we close the mouth so as to direct the whole of the inspired air through the nose; and then draw in the air by repeated short and sudden inspirations. This causes upward and abrupt rushes into the nasal cavities, the effect of which is to disturb the comparatively still air of the olfactory part of the nose, and to exchange some of it for the air containing the odorous substance. As soon as particles of this substance stimulate the olfactory nerve-endings, a sensory impulse is transmitted to the brain, and the sensation of smell is experienced. The olfactory nerves are unmyelinated, and pass to the hippocampal region of the brain, each to its own side.

Anosmia or loss of smell during a cold is sometimes due to the swollen condition of the mucous membrane surrounding the ethmoidal cavities, by which they are shut off from the common cavity through which the air passes.



Fig. 158.—Nerves of the Outer Wall of the Left Nasal Cavity.

In the figure are seen the first (olfactory) and fifth cranial nerves (superior maxillary branch).

Perversions of the sense of smell occur in some types of insanity.

Note that these organs of smell and taste are placed at the commencement of the alimentary canal, to give us further information concerning the wholesomeness of the food we are going to eat. Animals will reject their food if the smell is not considered satisfactory. Hence these organs of smell and taste are protective in function, as well as increasing our field of consciousness.

The organ of smell is little more than vestigial in man. On the other hand, in fishes, especially those that are predatory, the olfactory lobes are very large. Dogs, in whom the sense of smell is well developed, have a large pyriform lobe in the lower temporal area of the cerebrum. The olfactory receiving apparatus is probably not directional, as are the ears and eyes.

SUMMARY

THE TONGUE—a muscular organ in the floor of the mouth covered with mucous membrane, in which are embedded the receptor organs for taste.

Papillæ, sensitive cutaneous elevations for tactile and taste perception.

Filiform, fungiform, and circumvallate.

Nerves—for all cutaneous sensations + taste + motor to muscles.

Taste—anterior $\frac{2}{3}$, *via* chorda tympani branch of VII.

posterior $\frac{1}{3}$, *via* IX (Glosso-pharyngeal).

Movement—*via* XII (Hypoglossal).

Functions—mastication, speech, deglutition, taste.

SENSATION OF TASTE—afferent fibres, *via* VII, IX, cranial nerves.

1. **Taste buds**—receptor organs for taste. Nerve supply, VII and IX.
Cortical area for perception—hippocampal gyrus.

2. **Nature of sensations**—bitter, sweet, acid (sour), saline.

THE NOSE—the projection from the centre of the face.

External bony and cartilaginous framework—two nasal cavities.

Accessory sinuses (air cells)—frontal, ethmoidal, sphenoidal, maxillary.

Functions 1. The organ of smell—superior meatus only.

2. Part of the respiratory apparatus—for warming and filtering inspired air.

SENSATION OF SMELL—afferent fibres form the first cranial nerve.

1. **Receptor organs**—special olfactory cells in the mucous membrane covering the superior meatus.

2. Fibres from olfactory cells pierce cribriform plate of ethmoid bone to form olfactory tract which goes to the hippocampal gyrus of *same* side.

CHAPTER XXXV

THE EYE AND VISION

THE eye is an optical instrument (like a camera) and also a receiving apparatus, for ether (electro-magnetic) waves, within certain limits, the lower wave-length being about 800 millionths of a millimetre, and the upper 400 millionths of a millimetre, *i.e.* roughly a range of one octave only. Waves outside these limits are not perceived by the eye. Those below the lower limit form the **infra-red** (now used in photography), while still longer ones are wireless waves. Those above the upper limit constitute **ultra-violet** waves used in therapeutic medicine. Light between the above limits of wave-length produce different impressions on our consciousness which we call **colour**. The actual sensitive portion of the eyeball is that coat known as the retina (described later), all the rest being accessory. The retina really constitutes a receiving apparatus for the above-mentioned ether waves, absorbing their energy and converting it to nerve impulses which are conveyed to the occipital cortex, there to enter into consciousness, as the sensation of light. The eyes of all vertebrates are fundamentally the same, only differing in small, but important details.

THE EYEBALL.—The receptor organ for vision lies in the *eyeball*, which, with its accessory structures, the muscles, blood-vessels, eyelids, nerves, fatty tissue, and lachrymal apparatus, completely fill the orbit or eyesocket.

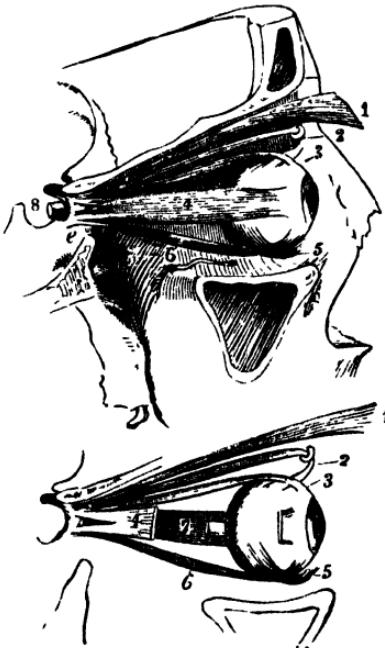
In front, the ball of the eye is protected by two movable folds of the skin called the upper and lower eyelids. In most birds, and some mammals and fishes, there is a third semi-transparent eyelid, known as the nictitating membrane, of unknown function. The inner surfaces of the lids are lined by a mucous membrane called the **conjunctiva**, which is also reflected over the front of the ball. That lining the inner surface of the eyelids is called the **palpebral**, and that over the sclerotic is the **bulbar** conjunctiva. The upper eyelid is larger and more movable than the lower one, and it is chiefly by the elevation and depression of this lid that the eye is opened

and closed. The eyelids are closed by the contraction of muscular fibres which are arranged in the form of a ring around the eye. This circular muscle is called the **Orbicularis oculi** (Lat. *orbiculus*, a little circle). It is the sphincter

From Radium	Carbo-de discharge	SUNLIGHT (Terrestrial)				Spark discharges
γ RAYS	X RAYS	ULTRA VIOLET RAYS	VISUAL RAYS	INFRA-RED RAYS	ELECTRIC WAVES	Wireless Waves
Cancer Treatment	For Shadows of Organs	Tans Skin.	Sensation D of Light	Heat Providing	Diaathermy	

Fig. 159.—The Range of Electro-magnetic Waves.

The arrow shows the direction of increasing wave-length, or decreasing frequency (cycles/sec.).



Figs. 160 and 161.—The Muscles of the Right Orbit.

e, sphenoid bone; 1, muscle which raises the upper lid; 2, pulley and tendon of the superior oblique; 3, tendon of the superior rectus; 4, external rectus; —partly removed in fig. 161; 5, inferior oblique muscle; 6, inferior rectus; 7, internal rectus; 8, optic nerve.

muscle of the eyelids. The lower lid has no special muscle to depress it, but the upper eyelid is raised by the contraction of a muscle which comes forward from the back of the orbit. This muscle is known as the **Levator palpebrae superioris** (Lat. *palpebra*,

the eyelid *levator*, a lifter up). It is evidently the antagonistic muscle to the *orbicularis oculi*.

THE MOVEMENTS OF THE EYES.—The eyeball is moved by six muscles, four of which are called *straight* muscles, and the other two *oblique*. The four *recti* (Lat. *rectus*, straight) come forwards from the back of the orbit, and are named superior, inferior, external and internal, from their positions. The superior rectus muscle turns the front of the eyeball upwards, the inferior rectus turns it downwards; and the external and internal recti turn the front of the eyeball outwards and inwards respectively. Of these the superior, inferior and internal *recti* are supplied by the oculo-motor nerve, while the external rectus is supplied by the sixth or abducent nerve.

The **superior oblique muscle** comes forward from the back of the orbit, and then, becoming tendinous, passes through a kind of pulley of fibres attached to the frontal bone. It then turns backwards and outwards, and is attached to the outer and back portion of the eyeball. Hence, when this muscle contracts, it turns the eyeball obliquely outwards and downwards. The **inferior oblique muscle** springs from the lower and front portion of the orbit, and passes obliquely backwards and outwards. By its contraction the front of the eyeball is turned upwards and outwards. The superior oblique is supplied by the fourth or trochlear nerve, and the inferior oblique by the oculomotor or third cranial nerve. In most of the movements of the eyeball at least two out of these six muscles are used.

THE LACHRYMAL GLANDS.—The front of the eyeball is kept clean and moist by a saline fluid which is secreted continuously by the lachrymal gland (Lat. *lachryma*, a tear). This gland is about the size of a small almond, and is situated in the upper and outer portion of the orbital cavity. It is lodged in a cavity (the *lachrymal fossa*) of the frontal bone. It is very similar to the parotid gland in structure, and is provided with several small ducts by which the *lachrymal fluid* is conducted to the upper surface of the eyeball. The reflex blinking of the eyelids wipes the *cornea* and *sclerotic*. The fluid gradually moves over the surface of the ball, assisted by every motion of the eyelid, till it reaches the inner angle formed by the eyelids, having carried with it any particles of dust which may have adhered to the eyeball. The lachrymal fluid now enters the *lachrymal sac* by means of two small *lachrymal canals*, and is then conveyed into the nasal duct, about 18 mm. long, which leads to the inferior meatus of the nose, where the contents are discharged.

Tear fluid has a marked bactericidal effect.

When there is a hyper secretion of the lachrymal fluid, such as may arise from irritation of the conjunctiva by powerful vapours, etc., or from some strong mental emotion, the nasal duct cannot convey away the fluid as rapidly as it is secreted.

The tears then accumulate between the eyelids and the eyeball, and at last roll in drops over the cheeks. This condition is known as epiphora. It may also occur if the lachrymal duct is blocked with mucus.

It should also be mentioned that, as well as this watery lachrymal secretion there is also a greasy secretion from a row of sebaceous glands (*Meibomian glands*), which lie at the back of each eyelid.

In addition to the muscles mentioned above, the ball of the eye is protected and supported by a large quantity of loose **fatty**

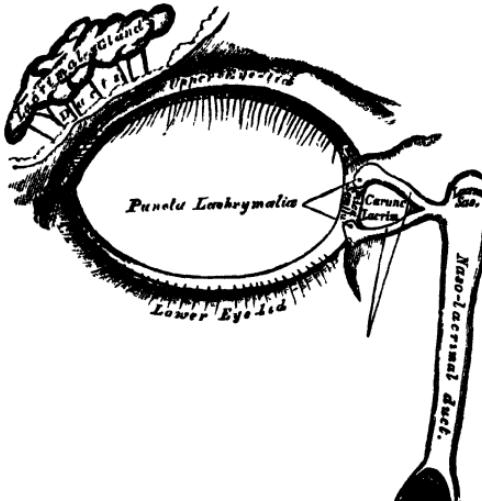


Fig. 162.—The Lachrymal Apparatus, right side.

and connective tissue, which, acting like a cushion or pad, serves to deaden the effect of pressure or blows.

THE STRUCTURE OF THE EYEBALL.—The general form of the eyeball is globular, but the corneal portion projects somewhat, being a portion of a smaller sphere. The eyeball measures about 20 mm. in diameter.

The eyeball has **three distinct coats**. The external consists of the *sclerotic coat* and the *cornea*, the middle coat is formed by the *chorioid membrane*, the inner is termed the *retina*. There are also other structures which must be described, such as the *iris*, *lens* and *humours*.

1. (a) **THE SCLEROTIC COAT** (Gr. *skleros*, hard) or white of the eye is a strong opaque fibrous membrane which

extends over the whole of the ball with the exception of about one-sixth of its surface in front. This coat is the thickest, and by far the strongest, and is the one on which the maintenance of the form of the eye depends. Its external surface is white, and covered with endothelium continuous with that lining the inner surface of the eyelids, while its inner surface is pigmented and hence called the *lamina fusca*. Behind, it is pierced by the optic nerve. Around the point of exit of the optic nerve are numerous small apertures for the transmission of nerves and blood-vessels. In front, the sclerotic coat is continuous with the cornea.

(b) **THE CORNEA** (Lat. *corneus*, horny—a transparent horny coat) is continuous with the sclerotic coat, and covers the anterior sixth of the eyeball. It forms the prominent spherical surface before mentioned, and is clear and transparent. It is not supplied with blood-vessels. It is almost circular in outline, and is convex anteriorly. It has a smaller radius of curvature (8 mm.) than the sclerotic. Although it has no blood-vessels, it is well supplied with sensory nerves (pain only). Its nutrition is secured by diffusion of fluid from the vessels in the sclerotic coat.

2. **THE CHORIOID COAT** is a dark brown membrane lying within and against the sclerotic. It consists of a thickly set network of blood-vessels, supported by connective tissue, and loaded with cells containing a dark pigment or colouring matter. It invests the posterior five-sixths of the eyeball. In some animals there is seen a brilliant iridescent appearance in the eyes, especially when a light shines on them in the dark—as when motoring along a country road at night. It is due to a layer of iridescent cells lying within the choroid, and known as the *tapetum*, the function of which is not known. A muscular body, known as the *ciliary body*, connects the choroid to the iris in front. It has two sets of involuntary fibres, radial and circular. The choroid is pierced behind by the optic nerve. Its outer surface is loosely connected to the sclera, while its inner surface is attached to the pigmented layer of the retina. One use of this coat, as we shall presently learn, is to darken the chamber of the eye, and thus prevent the internal reflection of light and so interfere with clear vision. Just before the choroid coat reaches the edge of the cornea, it becomes modified, being raised into a number of ridges which constitute the *ciliary processes*. They are arranged in a circle, forming a kind of frill behind the iris and around the margin of the lens. These

processes are similar in structure to the choroid, their posterior surfaces being covered with pigment cells. The ciliary processes contain small glands which secrete the aqueous humour.

3. **THE IRIS** (Gr. *iris*) is the circular muscular curtain, seen through the cornea, which gives the colour to the eye. It is

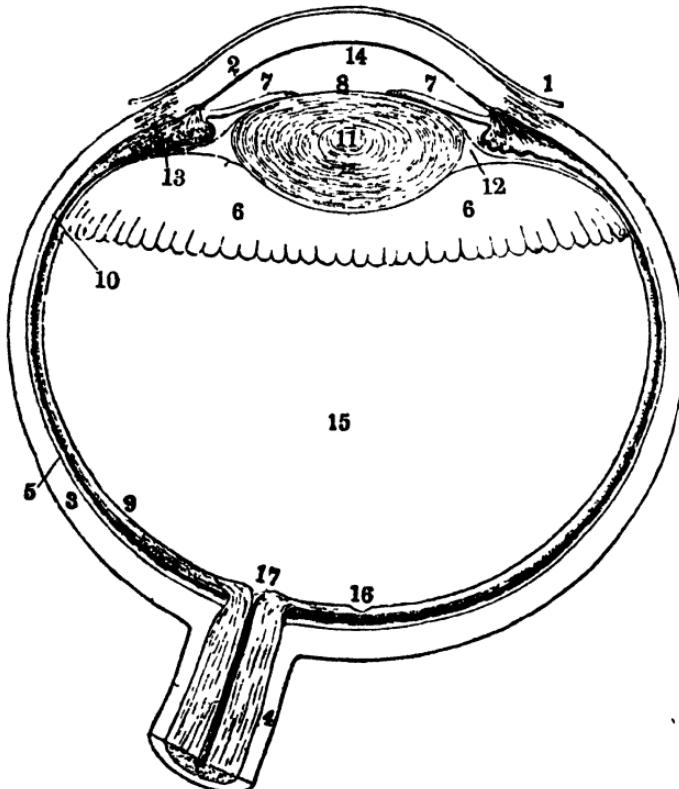


Fig. 163.—Plan of the Right Eye—divided horizontally.

1, conjunctiva ; 2, cornea ; 3, sclerotic ; 4, sheath of the optic nerve ; 5, choroid ; 6, ciliary processes ; 7, iris ; 8, pupil ; 9, retina ; 10, anterior limit of the retina ; 11, crystalline lens ; 12, suspensory ligament ; 13, ciliary muscle ; 14, aqueous chamber ; 15, vitreous chamber ; 16, yellow spot ; 17, blind spot.

continuous with the ciliary body and choroid. Its posterior surface is covered by two layers of pigmented columnar epithelium known as the uvea (Lat. *a grape*). Pigmented cells are also scattered about the iris. It is the reflection of light from these which give the characteristic colour to the iris, the colour

being determined by the amount and distribution of the pigment. In albinos there is no pigment, and hence the vascular choroid shows up well, giving the eyes their pink colour as seen in albino rabbits. Its centre is perforated, leaving a circular aperture called the pupil. Hence the pupil is not a structure, it is a hole in a structure—the iris. Not all pupils are circular—that of the cat is a vertical slit, and the frog transversely oval. The iris is a thin, circular contractile membrane. It is provided with unstriped muscular fibres, some of which are arranged in a ring around the pupil, forming the sphincter pupillæ,

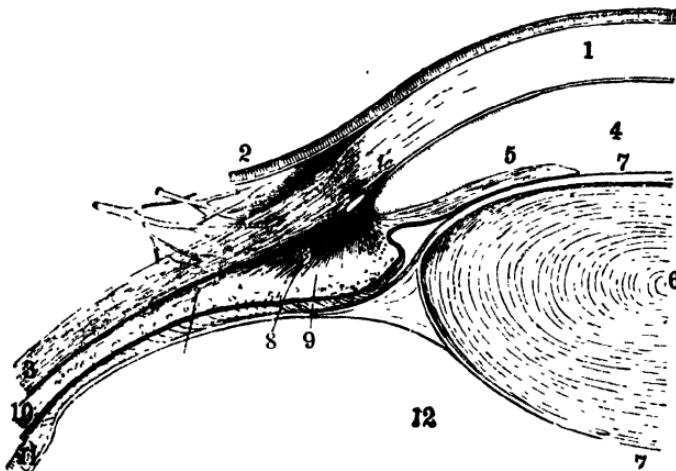


Fig. 164.—The Connections of the Cornea, Sclerotic, Iris, Ciliary Muscle, Ciliary Processes and Lens.

1, cornea ; 2, conjunctiva ; 3, sclerotic ; 4, aqueous chamber ; 5, iris ; 6, centre of the lens ; 7, capsule of the lens ; 8, ciliary muscle ; 9, ciliary process ; 10, choroid ; 11, retina (anterior portion) ; 12, vitreous chamber.

while the others are radiating, forming the dilator pupillæ. When the circular fibres contract, the pupil is made smaller ; when the radiating fibres contract the pupil is dilated. By these means the diameter of the pupil is made to vary from $\frac{1}{3}$ to $\frac{1}{20}$ of an inch, and the quantity of light admitted into the eyeball is regulated. It should be noted that the third cranial nerve (oculo-motor) supplies the sphincter pupillæ, while the sympathetic supplies the dilator. The iris thus acts as a stop or diaphragm, of use when the eye has to be adjusted for vision at different distances. This occurs automatically, and is known as the “accommodation reflex.”

The pupil contracts when the eye is exposed to a bright light. This is known as the **light reflex**, and is clearly protective in function. Also it contracts when it is accommodated for near objects, in order, as explained above, to obtain sharper definition. It is also contracted during sleep. Conversely it is dilated when in the dark, when adapted for distant vision, and also during emotional states. These latter stimulate the sympathetic system of nerves which control the dilator pupillæ.

4. **THE RETINA** is a delicate membrane which lies within the chorioid coat and is the essential part of the receiving apparatus for light waves. It is extremely thin and transparent, and covers the whole of the chorioid with the exception of the *ciliary processes*, and apparently ends as a series of jagged processes called the ora serrata. It consists of the enlarged commencement of the fibres of the optic nerve, supported by an extremely delicate connective tissue.

The retina is a soft, transparent structure of a purple tint due to the presence of a colouring matter known as **rhodopsin**, only found in association with those structures known as rods (see below). It is bleached on exposure to light. Exactly opposite the centre of the pupil is a yellowish spot, the **macula lutea** (Lat. *macula*, a spot; *luteus*, yellow). In the centre is a depression called the fovea centralis. Here the retina is thinnest and consists of cones only and no rhodopsin. It is the spot of most distinct vision. For this reason we are constantly moving our eyes so as to bring the image on this spot. About 3 mm. to the nasal side of the macula is the point of exit of the optic nerve, called the **optic disc**. Through the centre of this disc runs the blood-vessels (artery and vein) which supply the retina. The optic disc is quite insensitive to light and is known as the **blind spot**. There are many layers of nerve cells in the retina, but the essential structures are peculiar-shaped bodies known as the rods and cones. These receive the light rays, and, under the influence of the latter, nervous stimuli proceed from them to the commencement of the optic nerve fibres, and so eventually to the cerebral cortex, where they are translated into sight. It is supposed that the cones are concerned with day-vision (in which colour is predominant), and the rods with night-vision, where colour largely vanishes.

The outermost layer of the retina is also pigmented. This appears to act as an absorbent of light. It is known as **fuscin**.

5. **THE CRYSTALLINE LENS** is a doubly convex,

transparent, solid body close behind the iris. Its front surface, which is less convex than the back, is almost in contact with the iris; and a space is enclosed between these structures and the cornea in front. The lens measures about 8 mm. in diameter and consists of layers, one within another, like those of the onion. If the lens be hardened in alcohol, these layers may be easily separated from each other. The lens is surrounded by a thin, transparent and structureless membrane called the **capsule**, and is kept firmly in its place by a strong and elastic frame called the **suspensory ligament**, which extends from the capsule to the ciliary processes of the choroid. This ligament keeps the crystalline lens in a state of tension. The shape of the lens varies in different animals, e.g. in fishes it is globular, since they are naturally short-sighted.

6. **THE CILIARY MUSCLE.**—Muscular fibres radiate backwards from the junction of the cornea and the sclerotic, and are attached to the outer surface of the choroid coat. These fibres form the **ciliary muscle**. When they contract they pull the choroid forward, causing the suspensory ligament to relax. This in turn allows the crystalline lens, which is also elastic, to shorten its diameter and become thicker and more convex. The thickening of the lens shortens its focal length and enables the image of near objects to be focussed on the retina. This is known as *accommodation*.

7. **THE HUMOURS.**—The space between the cornea in front and the iris and lens behind is filled with a saline fluid known as the **aqueous humour**. The globe of the eye, forming about four-fifths of the whole, behind the crystalline lens is filled with a transparent semi-solid substance called the **vitreous humour** (Lat. *vitreus*, glassy). The vitreous humour fills the concavity of the retina. It has a hollow in front, the **hyaloid fossa**, to accommodate the lens. It consists mostly of water, with a trace of salt and protein. Its function is to keep the eyeball taut, otherwise its optical properties would cease to exist. There are no blood-vessels in the vitreous humour, hence its nutrition must be carried on by exudation from the retinal and ciliary vessels. The humour is contained in a thin, transparent membrane, the **hyaloid membrane** (Gr. *hualos*, glass). The aqueous humour is constantly being renewed, not so the vitreous.

8. **THE EYELIDS** or *palpebrae* are two movable cutaneous curtains (upper and lower) lying in front of the eyeball. Their purpose is to cover up the eyes during sleep, in the presence of too powerful a light, or in threatened damage to the eye.

THE FORMATION OF AN IMAGE ON THE RETINA.—The cornea, aqueous humour, lens, and vitreous humour form a system of lenses, whose object is to focus images upon the yellow spot of the retina. Variations in the thickness of the lens enable the accurate focussing to be maintained from whatever distance one may view an object. The image, as in a camera, is upside down and reversed, but the mind interprets this in association with all our other senses, so that no confusion arises. The recognition of colour, too, is a psychological problem.

ACCOMMODATION may be defined as those changes which occur in the eye in order that *near* objects may be focussed on the retina.

In the eye the retina is the screen on which the images fall ; but this screen is not moved forwards and backwards as in the photographer's camera. If we look at an object at a certain distance, we see that object distinctly because its image is distinct on the retina ; but other objects in the same direction which are either nearer or more remote are more or less indistinct. If we now direct the attention to another object nearer than the first, the image of this object becomes sharp on the retina. And, since the retina has not moved, the refractive power of the eye must have increased in order to "focus" this nearer object. This change has been brought about by the contraction of the ciliary muscles acting indirectly on the lens. When we turn from near to distant objects, the opposite changes take place. The ciliary muscle relaxes, the suspensory ligament is pulled towards the edge of the choroid, and the lens becomes less convex. Strictly speaking, it can be shown that it is mainly the front or **anterior surface** of the lens which alters its shape, not the back surface. The anterior surface becomes more convex or has a smaller radius of curvature. This has the effect of increasing the refractive power of the eye, so that whereas the image would otherwise have been brought to a focus *behind* the retina, it is now so much more refracted that it just falls exactly on the retina. Thus the adjustment of the eye depends on the ciliary muscle and its consequent action on the crystalline lens. It is interesting to note that Nature adopts other ways of bringing about accommodation in other creatures. For instance, fishes are normally short-sighted, and they accommodate for *distant* objects by moving the lens towards the retina, by means of a special muscle, the **retractor lentis**. Moreover, in them the lens only serves to produce an image, while in mammals it is brought about chiefly by the cornea.

DEFECTS OF VISION.—These are of two varieties—those which are inherent in all spherical lenses, and those due to defects in the eye itself. It is only these latter **physiological** defects which are here considered.

1. **Myopia.**—In some persons the eyeball is a little longer than usual, and in a few the refractive power of the crystalline lens is above the average. In these cases the retina is too far back for the image to be sharply defined, *i.e.* the axis of the eyeball is too long, and consequently the vision is indistinct. Such persons are said to be **short-sighted** or **myopic**, and they may remedy their defective vision by wearing concave glasses, which cause rays of light to diverge or, at any rate, to become less convergent.

2. **Hypermetropic.**—The converse condition is also found, viz. in some individuals the axis of the eyeball is too short, with the result that it is only when they look at a distant object that they can recognise it. Near objects are only imperfectly focussed on the retina. Such persons are said to be **long-sighted** or **hypermetropic**. The remedy is to wear convex glasses, which produce convergence or less divergence of the light rays, which naturally come to an earlier focus than parallel or divergent rays. It should be mentioned that normal eyesight is known as **emmetropia**.

3. **Presbyopia.**—As age advances the crystalline lens becomes harder, loses its elasticity, and cannot thicken, hence power of accommodation is lost. The refractive power being as a consequence decreased, the retina is not far enough back to receive the sharply-defined image of near objects. Such individuals are said to be **old sighted** or **presbyopic** and

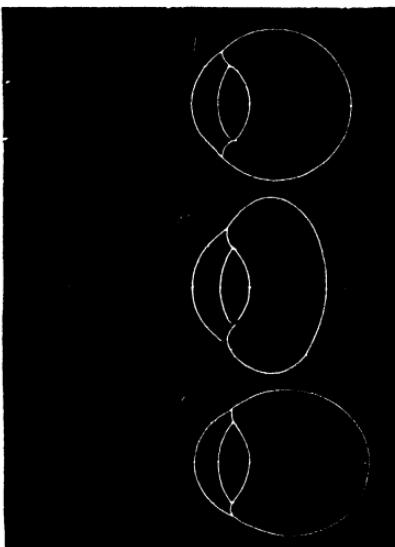


Fig. 165.—Diagrams of Course taken by Parallel Rays on entering the Eye (Starling's *Principles of Physiology*).

A, an emmetropic; B, hypermetropic; and C, a myopic eye.

should wear convex glasses to assist the convergence of the rays, the remedy being the same as with hypermetropes.

PSYCHOLOGY OF VISION.—It may now be asked, if the images of objects on the retina are inverted, how is it that we do not see the objects themselves inverted? In answer to this we reply that we do not *see* with the retina, but with the *cerebral cortex*. Light energy is absorbed by the nerve-endings in the retina (rods and cones), but there is no sense of vision

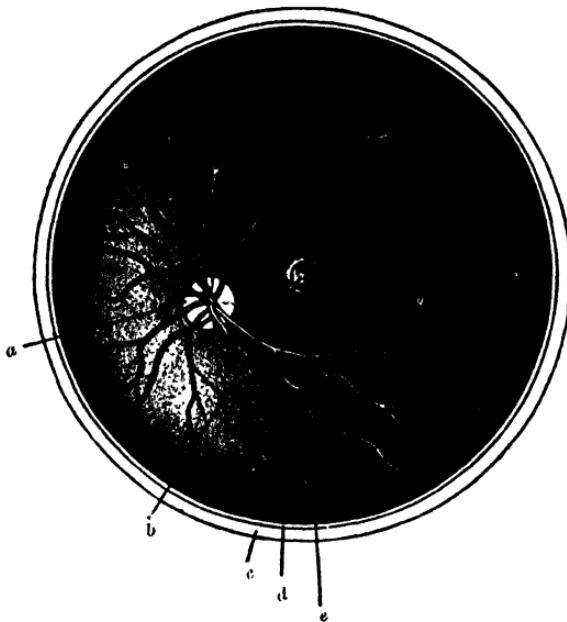


Fig. 166.—View of Fundus of Left Eye.

a, optic disc; b, macula lutea; c, the sclerotic coat; d, the choroid; e, the retina.

The veins appear darker than the arteries.

Note that the optic disc is slightly below and internal to the macula lutea.

until this energy is converted into and transmitted as a nerve impulse along the optic nerve and reach the occipital portion of the cerebrum, where the cortex converts the nerve impulses into the sensation of sight. As we are quite unaware of this retinal inversion, the cerebral cortex merely translates it in accordance with our ideas of relative position gained by general experience.

The optic nerve leaves the back of the eyeball at a point about $\frac{1}{15}$ of an inch from the yellow spot on the nasal side. This point is insensitive to light, and is known as the blind spot;

or **punctum cæcum**, discovered by the abbé Mariotte. To prove this, close the left eye, and look steadfastly on the left dot below with the right eye, holding the page at a distance of about a foot.

Now move the book *very slowly* towards the eye, keeping it still steadily fixed on the left dot. At a certain point (generally about 6 inches from the eye) the right dot will suddenly disappear, owing to its image falling on the blind spot ; but, on bringing the book nearer, it will reappear as its image leaves this point. With a little ingenuity the area of this spot, and its distance from the fovea, can be determined.

The **retina has the power of retaining the impressions made on it** for a short time—about one-eighth of a second. Consequently the falling raindrops often look like lines, the spokes of a rapidly revolving wheel do not hide objects behind them, and a lighted stick moved very rapidly appears as a line of light. It is owing to this fact that cinematography is possible, and no doubt, in time, we shall have chromatic cinema shows.

After or secondary images are due to the subsequent effects of retinal stimulation. These are divided into **positive** and **negative**. The former resemble the original image in colour and brightness. If one looks at a rapidly rotating fly-wheel, the individual spokes are not seen, but appear to be fused. Again, if one looks at a bright white object and then shut the eyes, a gradually fading away positive after image is seen. They are best seen on awaking from sleep. Negative after images resemble the original in form, but differ in colour and brightness. Look intently at a coloured object and then turn your gaze upon a uniform grey background. The negative after image is seen in its complementary colour, *e.g.* red and green are complementary, so are blue and yellow.

White light is composed of a multitude of colours—the colours of the rainbow or spectrum—as may be shown by allowing a beam of such light to pass through a prism of glass. If we look steadily for some time at a bright red spot on a sheet of white paper, and then turn the eyes aside to a clear portion of the paper, or to the ceiling, we see a *green* spot. The sensitivity of that portion of the retina on which the red rays fell has been exhausted so far as those rays are concerned, and it remains sensitive only to the other colours which compose white light. Consequently, when the white light from the paper falls on the

FROM THE REPORT OF THE INFLUENCE OF SCHOOL BOOKS
UPON EYESIGHT (BRITISH ASSOCIATION, 1913).

Specimens of Types.

This type may be used for books to be read by children under seven years.

This type may be used for books to be read by children from seven to eight years old.

This type is suitable in size for books to be read by children from eight to nine years old.

This type is suitable in size for books intended for readers over nine years old.

This type is suitable in size for books intended for practised readers over twelve years old.

This line is, for instance, comparatively easy to read whereas this is probably considerably more difficult.

exhausted portion of the retina, the red rays produce no effect, and we see the **complementary colour** to red ; that is, the colour produced by the combined effect of all the *other* rays of the white light. Conversely, if we exhaust a portion of the retina with green rays, we produce the complementary *red* image. These, of course, are negative after images.

COLOUR BLINDNESS or **hypochromatopsia** is inability to distinguish between two or more colours, different frequencies affecting the retina in exactly the same manner. The commonest defect is inability to distinguish between red and green. Hence, colours which appear different to normal people, are the same to those who are colour-blind. It is obvious that this condition is very important, both theoretically and practically. Engine drivers depend on coloured lights for their guidance at night, so that they must recognise colour without any means of comparison. The defect probably lies in the retina. Many colour-blind people are as sensitive to as great an extent of the spectrum and with equal intensity, as with normal people. Hence their condition is really one of failure to differentiate certain wave-lengths. They are therefore hypochromatic. Over 4 per cent. of all adult males are said to be colour-blind. Hence traffic signals should differ in shape as well as in colour and position.

VISION TESTS are carried out in two ways :—

(a) By *Snellen's Sight Tests*, which are meant for distant vision. This consists of rows of standardised letters printed on a card. Each row has its letters of the same size, with a graduation in the sizes from top to bottom. The patient whose sight is to be tested stands with his back to a good light, and uses one eye at a time. Over each row is a figure giving the distance in metres at which a normal person would be able to read the letters. If now, standing 6 metres away, he can only read the row corresponding to a distance of 9 metres, his vision is defective and recorded as 6/9. This means that he can only read at 6 metres what should be read at 9 metres.

(b) By *Jaeger types* for near vision—see opposite page.

SUMMARY

EYELIDS—folds of skin to cover eyes, closed by orbicularis, raised by levator palpebræ superioris ; lined by mucous membrane.

MUSCLES—extrinsic to move eyeball, intrinsic for accommodation.

i. **Extrinsic**—in three pairs :—

- a. Sup. Obl. (eye down and out), Inf. Obl. (eye up and out).
- b. Sup. Recti (eye up), Inf. Recti (eye down).
- c. Ext. Recti (eye out), Int. Recti (eye in).

2. **Intrinsic**—within eyeball itself.

- a. Ciliary muscle controls accommodation *via* curvature of lens.
- b. Iris—radial fibres dilate pupil, circular fibres constrict it.

LACHRYMAL GLAND—moistens eyeball, bacteriophage.

Gland in upper outer part of orbit, duct runs to inferior meatus.

COATS—for optical, protective and nutritive purposes.

1. **Outer**—in two portions :—**Cornea** ($1/6$ eyeball) transparent, for light waves ; **sclerotic** ($5/6$ eyeball) is tough, protective, and for insertion of muscles.
2. **Middle—chorioid**, vascular (nutrition), pigmented (camera obscura).
Iris—thin muscular diaphragm to vary admission of light.
 - a. Circular fibres—constrict pupil *via* parasympathetic (III).
 - b. Radial fibres—dilate pupil *via* sympathetic.
3. **Inner—retina**, the receptor organ for absorption of light energy.

The rods and cones are the actual receptor elements.

Two pigments—**visual purple** (rhodopsin), for night vision ; **fuscin**, for absorption of light.

LENS—double convex lens just behind iris. Controlled by ciliary muscle, thickens in accommodation.

Accommodation—those changes in eyes when adapted for near vision, viz. convergence of the eyeballs, and contraction of the pupil and the ciliary muscle.

HUMOURS—keep eyeball taut for distinct vision, nutrition, drainage.

- a. **Aqueous**—between iris and cornea, watery secretion from ciliary gland.
- b. **Vitreous**—behind iris (four-fifth eyeball), jelly-like, distends eyeball.

DEFECTS OF VISION.

- a. Optical, therefore inevitable—spherical and chromatic aberration.
- b. Physiological—due to defects in eyeball or lens.
 - Short sight (myopia)—eyeball too long, image in front of retina ; remedy—concave spherical lenses.
 - Long sight (hypermetropia)—eyeball too short, image is behind retina ; remedy—convex spherical lenses.
 - Old sight (presbyopia)—lens inelastic, little accommodation, image behind retina ; remedy—convex spherical lenses.
 - Astigmatism**—variations in corneal curvature ; remedy—cylindrical lenses correctly oriented.
 - Blind spot—no vision at exit of optic nerve, for no rods or cones.
 - Yellow spot—most acute vision, only cones present.
 - Persistence of vision—leads to production of after images and to fusion of images—hence cinematography possible.
 - Colour blindness—usually a red-green confusion.

CHAPTER XXXVI

THE EAR AND HEARING—POSTURE AND EQUILIBRIUM

THE EAR consists of three parts: the *external portion*, the *middle portion* or *tympanic cavity*, and the *internal portion* or *labyrinth*. The latter, moreover, consists of two distinct parts, anatomically and physiologically. One is the **cochlea**, the

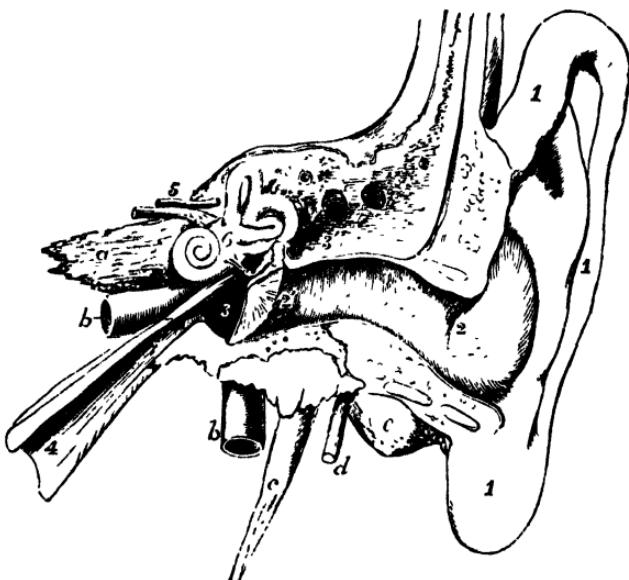


Fig. 167.—Diagrammatic front view of the Left Ear.

1, the pinna and lobe; 2 to 2', the external auditory meatus; 2', the tympanic membrane; 3, the cavity of the middle ear—above 3 is the chain of small bones; 4, Eustachian tube; 5, the facial and auditory nerves; 6, placed on the vestibule of the labyrinth, above the fenestra ovalis; a, c, e and f, portions of the temporal bone; b, internal carotid artery; d, branch of the facial nerve.

receptor organ for hearing, and the other is the **vestibule**, the receptor organ for equilibrium. The external and middle ears or portions are concerned merely in the collection, transmission and amplification of sound vibrations.

THE PHYSICS OF SOUND WAVES.—There are vibrations in air, not as with light waves in the ether which fills all space. Sound waves are really pressure waves in a material medium. Moreover, it should be realised that all broadcasting would be utterly futile if we were all deaf. The number of cycles or vibrations/second produced by a vibrating body is known as its **frequency**. The human ear can hear frequencies from approximately 16 to 20,000 c/s. Within these limits, the range of notes used in music is from about 30 to 4,000 vibrations per second. An ordinary seven octave piano ranges from about 27 to 3,480 c/s., while gramophone reproduction is about 50 to 5,000 c/s. The upper limit of hearing is easily determined by a Galton's whistle.

It has been determined, from research on the design of loud speakers, that if all frequencies from about 40 to 10,000 are correctly reproduced, the ear is unable to detect the loss of the others. Further, it takes a really good ear to detect any falling off in quality even if the cycles are cut down to 60 to 8,000. Here, as with ether waves, it is more fundamental to deal with cycles/second, rather than wave-lengths.

THE ANATOMY OF THE EAR.—We must now consider in detail each of the three parts:—

i. **THE OUTER EAR** consists of the *pinna* (Lat., a *wing*), that part which projects from the side of the head, and the *auditory canal* (external auditory meatus).

The **pinna**, in some mammals (but not man), is especially adapted for the collection of sound waves which are reflected by it into the canal. It consists of a cartilaginous framework, surrounded by a certain amount of fatty tissue and a few weak muscles, the whole being covered with integument. The pinna is absent in all vertebrates except mammals. It is not a structure essential to hearing.

The **auditory canal** extends inward from the pinna to a distance of about $1\frac{1}{2}$ inches. Its inner extremity is closed by a very thin membrane called the **drum of the ear** (or the **tympanic membrane**), which is stretched across it obliquely. The walls of the canal are formed in the outer one-third of its length by cartilage and in the inner two-thirds by bone, and are lined with a continuation of the skin. This skin, at the outer portion of the canal, is provided with small hairs, and also a number of glands, similar in structure to the sweat glands, which secrete the *cerumen* or *ear wax*. Both the hairs, which are inclined outwards, and the wax, tend to arrest dust particles. The purpose of this canal is to convey the sound waves to the drum of the ear, which is thus set into vibration.

To view the drum, one uses a speculum and reflecting mirror. The pinna has to be pulled upwards, backwards and outwards. In the living condition the tympanic membrane glistens like

mother of pearl, but if as in otitis media there is any inflammation it becomes of a reddish tinge, due to the dilated capillaries. Only the handle of the malleus can be distinctly seen.

2. THE MIDDLE EAR or TYMPANIC CAVITY (Lat. *tympanum*, a drum) is a small irregular cavity in the petrous portion of the temporal bone. It is separated from the auditory canal by the tympanic membrane, and contains a chain of three small movable bones or ossicles by means of which the vibrations received by the drum are transmitted across the cavity to the inner ear. They act as an amplifier.

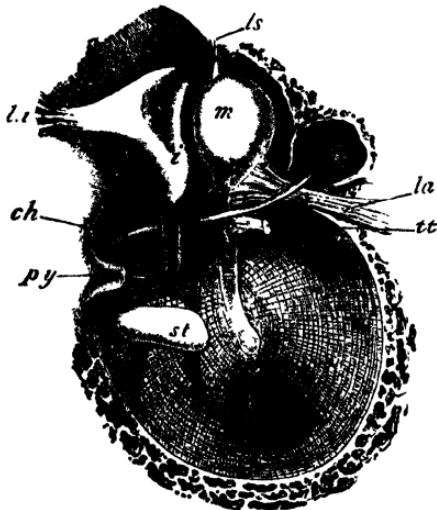


Fig. 168.—The Left Tympanic Membrane and the Auditory Bones.

m, malleus; *i*, incus; *st*, stapes; *py*, pyramid from which the tendon of the muscle of the stapes emerges; *tt*, tendon of the tensor tympani; *la*, anterior ligament of the malleus; *ls*, superior ligament of the malleus; *li*, ligament of the incus; *ch*, branch of the facial nerve.

The middle ear is lined with mucous membrane, which sometimes becomes inflamed, leading to the condition of otitis media, mentioned above.

THE EAR BONES are three in number, called respectively the *malleus* or *hammer*, the *incus* or *anvil*, and the *stapes* or *stirrup*. The handle of the *malleus* is attached throughout its length to the drum of the ear, and consequently vibrates with it. The vibratory motion is then taken up by the *incus* and the *stapes* in turn. This last bone fits into an opening known as the *fenestra ovalis* in the inner wall of the tympanic cavity, thus transmitting the sound vibrations to the inner ear.



Fig. 169.—The Right Bony Labyrinth.

1, vestibule; 2, *fenestra ovalis*; 3, 4 and 5, semicircular canals; 6, 7 and 8, the cochlea; 9, *fenestra rotunda*. The smaller figure below shows the natural size.

THE EAR MUSCLES are two small muscles passing from the walls of the tympanic cavity. One is attached to the handle of the malleus near its root, and serves to tighten up the tympanic membrane. It is called the **Tensor tympani**, and is supplied by a branch of the fifth cranial nerve. The other muscle is inserted into the neck of the stapes, and is called the **Stapedius**. It is supplied by a small branch from the seventh or facial nerve. Its action is not fully understood, though some consider it may be to counteract the tensor tympani. These muscles are used to modify the mechanical conditions of the middle ear such that faint sounds are amplified, and loud sounds damped, *i.e.* as a volume control.

The **middle ear** contains air, and communicates with the nasal portion of the pharynx by means of the **Eustachian tube**, which is about $1\frac{1}{4}$ inches

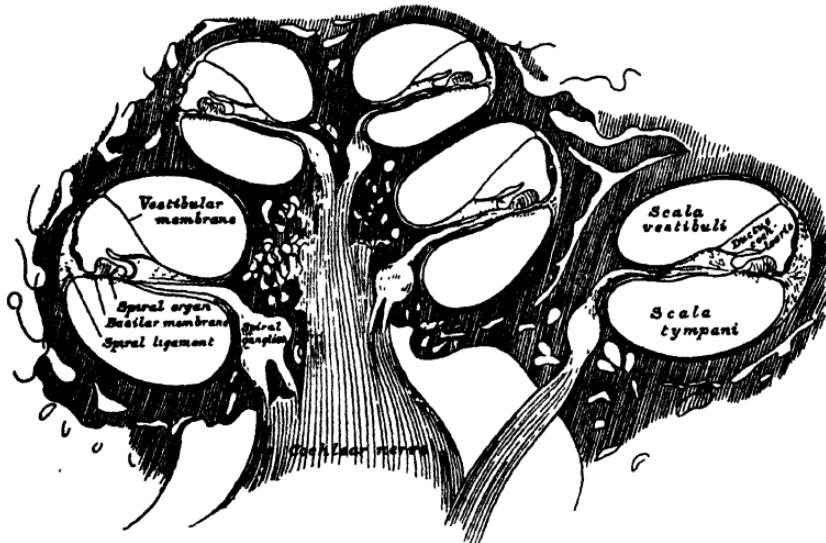


Fig. 170.—Longitudinal Section of the Cochlea (diagrammatic).

long, and whose direction is downwards, forwards and inwards. It is formed partly of bone, cartilage and fibrous tissue. By this arrangement the air pressure is generally equalised on the two sides of the drum. The Eustachian tube, being narrow, is easily blocked by the meeting of its opposite walls; and if this occurs at a moment when the pressures on the internal and external surfaces of the drum are unequal, a peculiar sensation is experienced, and hearing is for the time defective. Performing the act of swallowing, the tube is opened and the normal pressure restored.

Sometimes a pharyngitis spreads up this tube. The resulting inflamed and swollen mucous membrane blocks the tube, and may cause some degree of temporary deafness.

3. **THE INNER EAR** consists of a very complex cavity also hollowed out of the temporal bone (the *osseous labyrinth*),

which contains a similar cavity (the *membranous labyrinth*) (Gr. *labirinthos*, a maze) surrounded by a fluid, the perilymph.

The *membranous labyrinth* consists of three parts : the *vestibule* (Lat. *vestibulum*, an entrance), the *semicircular canals* and the *cochlea* (Lat., a snail).

(a) **THE COCHLEA** contains the essential organ of hearing, for its destruction causes deafness, and no loss of equilibrium, while the converse is the case if the vestibule and semicircular canals are destroyed.

The cochlea or anterior portion of the labyrinth is a spiral tube, 30 mm. long, and in shape like the shell of a snail, consisting of two and a

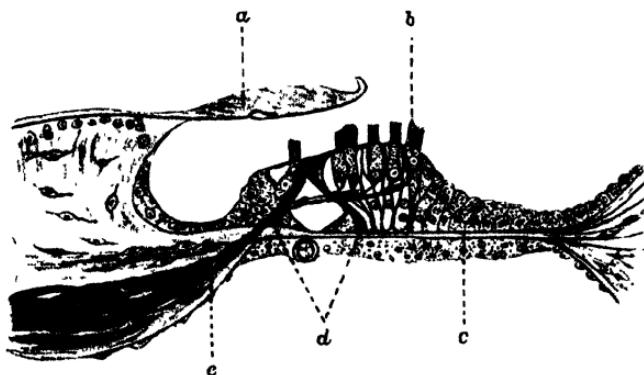


Fig. 171.—Structure of the Organ of Corti (diagrammatic).

a, membrana tectoria ; b, hair cell ; c, basilar membrane ; d, rods of Corti ; e, cochlear nerve fibres and (on the left) spiral ganglion.

half turns, wound round a central pillar called the *modiolus* (Lat., the nave of a wheel). There is an opening from the cranial cavity into the temporal bone which runs to the base of the modiolus. This is the **internal auditory meatus**, whose function is to convey blood-vessels, and the facial and auditory nerves. The latter passes through a series of minute holes in the base of the modiolus. A thin layer of bone projects from the modiolus, following the convolutions of the cochlea, and two membranes stretch from this long plate to the outer wall of the cochlea. In this way the cochlea is divided into three compartments, the *scala vestibuli* uppermost, the *scala tympani* lowest and the *scala media* between. The latter is part of the membranous labyrinth, and is filled with endolymph, while the two former belong to the bony labyrinth, and are filled with perilymph. The cochlea communicates with the tympanic cavity by an opening called the *fenestra rotunda* (round window), which is closed by a membrane.

In one of these membranes, the *basilar membrane*, lies the receptor organ for sound—the *organ of Corti*—a complicated arrangement of neuro-epithelial cells associated with the commencement of the auditory nerve

fibres (cochlear branch). By the varying pressure waves produced in the endolymph by the movements of the footpiece of the stapes, these cells are made to produce nerve impulses, which pass along the cochlear division of the eighth cranial nerve, and out *via* the internal auditory meatus to the superior temporal gyrus of the cerebral cortex, there to be translated into the sensation of sound. In fishes the internal ear is the only organ of hearing, and even this is in a very rudimentary condition. The sound waves travelling through the water are transmitted through the cranium. But in the air-breathing vertebrates an elaborate collecting apparatus is needed, for the air waves are fainter. The loudness or intensity of a sound varies with the density of the medium.

Branches of the **auditory nerve** supply fibres to the cochlea. The terminations of these fibres end in special cells and are provided with delicate hair-like processes projecting into the endolymph. These cells are collectively known as the **organ**

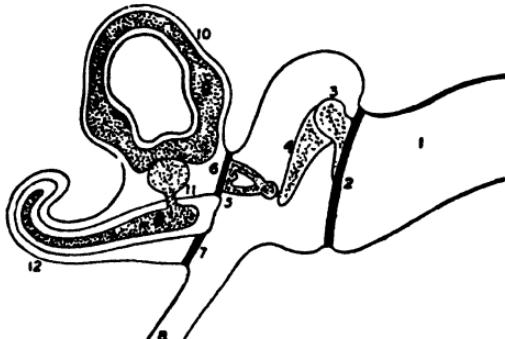


Fig. 172.—Diagram illustrating the relative positions of the various parts of the Ear.

1, external auditory meatus ; 2, tympanic membrane ; 3, malleus ; 4, incus ; 5, stapes ; 6, fenestra ovalis ; 7, fenestra rotunda ; 8, Eustachian tube ; 9, membranous labyrinth ; 10, semicircular canal ; 11, vestibule ; 12, cochlea.

of Corti, and they constitute the receptor organ of hearing. As stated before, sounds differ in respect of **pitch** (highness or lowness), **loudness** (intensity) and **quality**, *i.e.* whether it is a note produced by an instrument, animal or gun. The cochlea enables us to judge of all three of these properties of a musical note.

Moreover, "loudness" of a note is not wholly physical, but depends on the ear and hearer. That is, it is partly subjective.

THE MECHANISM OF HEARING.—We may now trace the path along which the sound vibrations travel. These sound waves pass down the *external auditory canal*, at the extremity of which they impinge against the *drum*. This vibrating membrane then communicates its motion to the

chain of small *bones*, by which the footplate of the stapes varies the pressure in the *perilymph* of the inner ear. This fluid communicates the vibration to the *endolymph*, and thence to the hair-like processes of the cells forming the organ of Corti. From these cells proceed the fibres of the *auditory nerve*. These cells are affected by the endolymph pressure waves, and they start nerve impulses along the cochlear nerve fibres, which goes to the cortex of the superior temporal convolution, there giving rise to the sensation of hearing. The amplitude at the *fenestra ovalis* is only about one-third that on the drum. This is necessary for the efficient transmission of power from air to a liquid, *i.e.* a sort of step down transformer analogous to the matching of a loud speaker to the output valve. Briefly, therefore, we may say the function of the internal ear is to convert pressure waves (within certain limits of frequency) into nervous impulses. Sound vibrations may also be transmitted to the auditory nerve through the bones of the skull, without penetrating the structures of the ear, as, for example, a tuning-fork held with its stem on the cranium or mastoid, or between the teeth. This is a valuable clinical test as to whether a case of deafness is due to the internal ear or not, *i.e.* nerve deafness as distinguished from middle-ear deafness.

In the normal way the sound of a tuning-fork may be heard at the meatus after it has ceased to be heard by bone conduction. If, however, the membrane or ossicles are defective the reverse is the case.

Binaural Audition.—Many experiments have been carried out to ascertain the capabilities of the ears in estimating the direction from which sounds emanate. In brief, it appears that it is easy to discriminate between sounds to the right or left without moving the head, but there is sometimes difficulty in deciding whether the sound is in front or behind. High notes are easily screened by small objects—as, for instance, the holding of the hand between oneself and an engine blowing off steam. Many animals have large pinnæ of trumpet shape which are well supplied with muscles, so that they can be moved in various directions. By this means a still better idea of the direction of a sound can be determined. In man the pinnæ have retrogressed—they have lost their trumpet shape, and the muscles possess but little action. Few individuals can voluntarily move their ears. Sound is therefore stereophonic, in the same way that vision is stereoscopic. One day we shall have cinema displays that are stereoscopic, naturally coloured and stereophonic.

(b) **THE VESTIBULE** is the central chamber of the osseous labyrinth; it communicates with the semicircular canals behind by five orifices, and the cochlea in front. It is separated in part from the tympanic cavity by an opening—the **fenestra ovalis** (the oval window)—and contains the membranous labyrinth, consisting of two little sacs—the utricle and saccule.

(c) **THE SEMICIRCULAR CANALS** are three tubes,

superior, posterior and external, which communicate with the vestibule by five openings. They are dilated at their ends, and two of them unite at one common extremity before entering the vestibule. These dilations are known as **ampullæ**.

The semicircular canals, on the other hand, are **kinetic** organs. As the head is moved about, there is produced a varying pressure of the endolymph on the hair cells in the ampullæ. Each of these cells is connected with the five origins of the vestibular nerve. This pressure variation is converted into nerve impulses, which pass to the cerebellum, there to be associated with other afferent impulses (described below) also concerned with equilibrium.

Fig. 173.—Plan of the Left Membranous Labyrinth. ($\times 2\frac{1}{2}$.)

1, utricle; 2, saccule; 3, cochlea. Black shading along cochlea is origin of auditory branch of 8th nerve.

Note that these three semicircular canals are mutually orthogonal, *i.e.* each is at right angles to the plane of the other two. By this means movement in *any* direction can be detected. This is in contrast with the utricle and macule, which have to do with a **fixed** position of the head and its relation to posture. A whole series of reflexes are set up both by any fixed position of the head or any movement of it (stopping, continuing or ceasing). It is therefore usual to group all these together under the heading of **stato-kinetic** reflexes.

THE MEMBRANOUS LABYRINTH lies within the osseous labyrinth, and agrees with it in general form. It consists of two membranous sacs—the utricle and saccule, the three semicircular ducts, and the scala media. The space between them and the bony wall is filled with a fluid called **perilymph** (Gr. *peri*, around; and *lympha*, clear water). The membranous labyrinth is itself filled with a liquid, the **endolymph**. A number of minute crystals of carbonate of lime, called **otooliths** (Gr. *ous*, the ear; and *lithos*, stone), are buried in the mucus overlying the neuro-epithelium (hair cells) of



the dilated portions or ampullæ of the semicircular canals (*cristæ*), and in the utricle and saccule (*maculæ*). In each ampulla is a collection of special neuro-epithelial cells, each provided with stiff hairs projecting into the endolymph. Around each cell are the commencement of the eighth nerve (vestibular branch).

Owing to the importance of the position of the head in maintaining posture, a special mechanism has been developed within the maculae. The otoliths press against the hair cells, which latter have nerve fibres in association with them. As the head moves about, there are produced different alterations in pressure of the otoliths on the underlying hair cells, which pressure changes are converted into nerve impulses—the latter being carried by the vestibular nerve, and so to the cerebellum. The utricle and saccule are known collectively as the **otolith** or **statocyst** organ, and is essentially a **static** organ, that is, it is concerned with the position relative to the body of the head at rest.

The vestibule is supplied by a special division of the eighth cranial nerve, known as the *vestibular* nerve. This nerve starts as arborisations around the nerve-epithelial cells of the membranous labyrinth. The fibres run out *via* the internal auditory meatus to the cerebellum. The function of the semicircular canals is that of recognition of our position in space, *i.e.* with reference to the direction of gravity. This is attained by stimulation of the nerve-epithelial cells mentioned by currents set up in the endolymph in the semicircular canals.

In diagram 173 the five dots show the parts supplied by the vestibular division of the eighth nerve, viz. the *maculæ* of the utricle and saccule, and the three *cristæ* of the semicircular canals.

THE MAINTENANCE OF POSTURE.—It will be convenient to collect together here the various afferent impulses which help in the maintenance of posture and equilibrium, viz.:

1. **The labyrinths**, as explained above.
2. **The eyes** are important sensory receptors in this respect. The *retinæ*, the extrinsic muscles moving the eyeball, and the mechanism of accommodation are all actively concerned.
3. **The muscles and joints** possess sensory nerve organs (tendon organs and muscle spindles), which give the cerebellum information concerning muscular movement and position. The nerve impulses generated do not usually enter consciousness.
4. **The skin**, by its tactile sensibility, helps also in the production of afferent impulses.

SUMMARY

EXTERNAL EAR—to collect sound waves, non-directional in man.

- a. **Pinna**—cartilaginous flaps of skin, usually not movable.
- b. **Canal**—30 mms. long, secretes wax, leads to tympanum (drum).

MIDDLE EAR—irregular cavity in petrous portion of temporal bone.

Bones—a chain of three (malleus, incus, stapes) to amplify and transmit air vibrations to fenestra ovalis.

Openings—two, both covered with membrane—fenestra rotunda leads to scala tympani, fenestra ovalis leads to vestibule.

Muscles—tensor tympani and stapedius. Concerned in volume control.
The former is supplied by V, and the latter by VII.

INTERNAL EAR—complex bony cavity containing closely fitting membranous chambers and tubes—perilymph outside, endolymph inside.

- a. **Vestibule**—the middle cavity, with two sacs—utricle and saccule.
Utricle—communicates with the semicircular canals.
Saccule—communicates with utricle and the cochlear canal
- b. **Semicircular canals**—in three mutually perpendicular planes.
- c. **Cochlea**—subdivided into three spiral canals (two and a half turns).

FUNCTIONS OF THE INTERNAL EAR—two separate and distinct mechanisms :—

- a. **Vestibular apparatus**—normal posture and equilibration.
Each has five sets of receptor organs (three canals, utricle, saccule).
Converts pressure variations due to postural movements into nerve impulses, and so to consciousness.
- b. **Auditory apparatus (cochlea)**—concerned with hearing.
Receptor organ—Corti cells—convert sound waves to nerve impulses.

NERVE SUPPLY—two different sets, anatomically united in VIII.

- a. **Vestibular N.**—arises from five receptor organs (masculæ, cristæ).
Fibres go to cerebral sensory cortex, and so to consciousness.
- b. **Cochlear N.**—arises from the Corti cells and goes to temporal lobe.

CHAPTER XXXVII

THE LARYNX AND VOICE

THE ORGAN OF VOICE is the larynx, a modification of the upper portion of the trachea. Articulate speech is peculiar to the human species. There is a special vibrating mechanism in the larynx, which is the essential means for the production of sound. It consists of a cartilaginous framework, the parts of which are movable on each other, the motion being produced by the contraction of various muscles. These cartilages are the **thyroid**, **cricoid** and the two **arytenoids**. The former two have already been described.

The highest (posterior) portion of the cricoid is surrounded by two pyramidal cartilages called the **arytenoid cartilages** (Gr. *arutaina*, a pitcher). These form movable joints with the cricoid, to which they are held by ligaments. They must also necessarily accompany the cricoid cartilage in all its movements.

The arytenoid cartilages are connected with the inner surface of the front part of the thyroid cartilage by means of two bands of elastic fibres which are embedded in folds of mucous membrane. These fibres form the so-called **vocal cords**, which are about 15 mm. long in man, and 11 mm. in woman. They are both attached to the thyroid cartilage close to the middle line, and consequently, when they are stretched, their edges are brought nearly parallel, so that only a thin slit or chink (*rima*), known as the **glottis** or *rima glottidis*, is left for the air to pass between them.

The **epiglottis** has nothing to do with the production of sound.

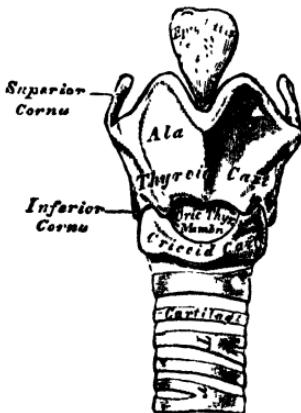


Fig. 174.—Anterior view of the Larynx and Upper Trachea.

It is a fibro-cartilaginous lid, the lower and narrower portion of which is fastened by a ligament to the front part of the thyroid cartilage. Its use is to close the upper opening of the larynx (the space between the vocal cords) during the act of swallowing, thus preventing particles of food or drink from passing into the trachea.

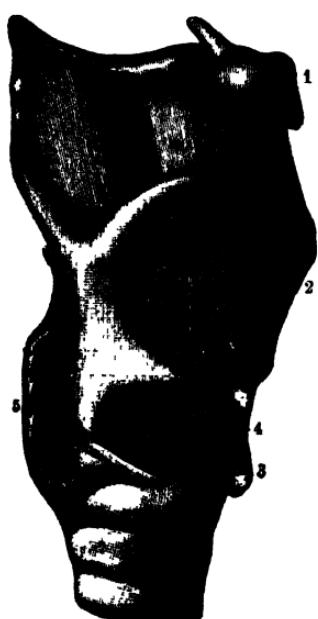


Fig. 175.—Side view of the Larynx.

1, hyoid bone ; 2, thyroid ; 3, cricoid —anterior part ; 4, crico-thyroid muscle ; 5, crico-arytenoid muscle.

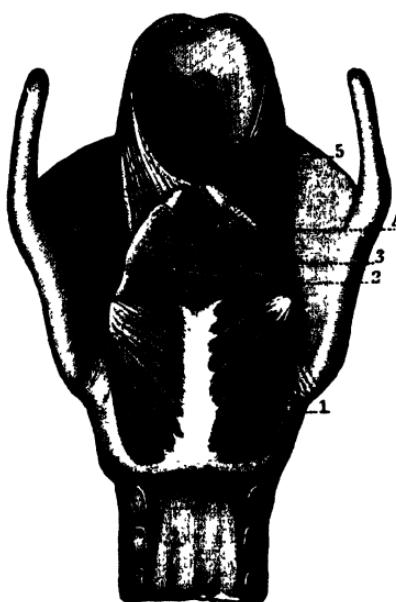


Fig. 176.—Posterior Muscles of the Larynx.

1, posterior crico-arytenoid ; 2, arytenoid ; 3, 4, oblique fibres passing round the edge of the arytenoid cartilages to form 5, the muscles which connect these cartilages with the epiglottis.

During quiet breathing the vocal cords are relaxed, the glottis is wide, and the air passes through freely. When we wish to speak or sing we cause certain muscles to stretch the cords and bring them near each other. Under these conditions the out-rushing air sets them in vibration, thus producing sound.

The contraction of the muscles connecting the thyroid with the arytenoid cartilages (*thyro-arytenoid* muscles) causes them to approach each other, and so relaxes the vocal cords. When the *crico-thyroid* muscles contract they cause the cricoid cartilage to rotate in such a manner as to tilt the arytenoid cartilages backward, and so to put the cords on the stretch. The

posterior crico-arytenoids are arranged to pull asunder the edges of the arytenoid cartilages to which the cords are attached and thus open the glottis. They are thus *abductor* in action. This opening of the glottis occurs in every act of inspiration. The *lateral crico-arytenoids* acting in the opposite direction, tend to bring the cords close to and parallel with each other, *i.e.* they are *adductors*. Hence the laryngeal muscles may be divided into two groups: those which open and close the glottis (the crico-arytenoids and the arytenoid); and those which regulate the tension of the vocal cords (the crico-thyroids and the thyro-arytenoids).

It is to be noted that the posterior crico-arytenoids are particularly important in that their paralysis would allow the vocal cords to approximate and so close the glottis, producing dyspnoea on attempting to take air into the lungs. The condition is known as inspiratory stridor from the curious harsh noise made.

The vocal cords may be thickened, thinned, stretched, relaxed, adducted and abducted.

PHYSICS OF SOUND.—

The *pitch* of a note depends on the number of vibrations or cycles per second; the more rapid the rate of vibration the higher the pitch. For example, 128 vibrations per second will produce the bass C; 256, the tenor C; 512, the treble C; and 1,024, the octave above; and so on. If we stretch a wire or string, we can make it vibrate by plucking it; and by either shortening the string or by increasing the stretching force we increase the rate of vibration, and so heighten the pitch of the note produced. The frequency also depends on the thickness of the string; the thicker the string, the less the rate of vibration. Hence the low pitch of the voice when we have a cold, for the cords are loaded with mucus. The

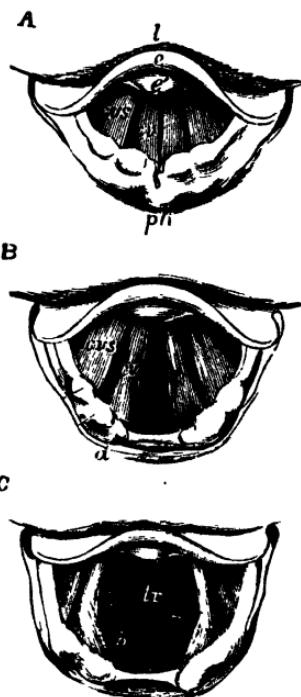


Fig. 177.—Three views of the Larynx during Life, as seen with the aid of the Laryngoscope. A, during the singing of a high note; B, during quiet breathing; C, while taking a deep breath.

l, base of the tongue; e, upper free part of the epiglottis; e', lower portion of the epiglottis; ph, front wall of the pharynx behind the larynx; a, tip of the arytenoid cartilage; cv, vocal cords; cvs, superior or false vocal cords, which do not aid in the production of the voice; tr, front wall of the trachea; b, commencement of the two bronchi.

loudness of the note varies with the amplitude of vibration of the cords depending on the force of the expiratory blast.

The *quality* of the note depends on various conditions, among which may be mentioned the shape of the mouth, the position of the tongue, the communication or non-communication between the pharynx and the nasal cavities, the position of the larynx, etc. Scientifically, quality is a complex of a note with some of its harmonics, giving an air of distinctness about the sound, which we learn as characteristic of the instrument producing it.

Speech is voice modified by changes in the pharynx, mouth and nose, while **whispering** is speech without voice. There is no vibration of the vocal cords, the lips and tongue being of great assistance into moulding the feeble air currents into faint speech. Articulate speech produces complicated pressure waves.

For speech to be good and intelligible it has been found that frequencies of 500 to 4,000 are necessary. This is of importance when we are dealing with reproduction from a loud speaker.

The **laryngoscope** is an instrument used to study the changes in the larynx during sound production, and also to examine it for diseased conditions. By its means a strong light is reflected from a concave mirror (with a central aperture for vision) into the throat, where a small mirror is so held as to reflect the light into the larynx and trachea, and back again to the observer.

In young persons the male larynx is constructed exactly like that of the female; but on reaching the age of puberty, the larynx of the male rapidly increases in size, becoming more prominent in the front of the throat. This enlargement causes a corresponding increase in the length of the vocal cords; hence the change in the pitch of the voice. The voice is said to "break," and the pitch is lowered. This is only part of a general alteration of the character of the individual at this age. The enlargement of the larynx and the deepening of the voice form part of the "secondary sexual characters," i.e. those which (apart from the primary sex organs) help to differentiate the sexes.

NERVE SUPPLY.—The larynx is supplied with motor and sensory fibres by two branches of the vagus:—

(a) The Superior Laryngeal nerve is sensory to the mucous membrane.

(b) The Inferior or Recurrent Laryngeal nerve is motor to the muscles.

SUMMARY

THE LARYNX—upper part of trachea, modified for voice.

1. Its cartilaginous walls are made up of :—
 - a. **The Thyroid Cartilage**—largest and uppermost.
 - b. **The Cricoid Cartilage**—shaped like a signet ring.
 - c. **The Arytenoids**—rest on upper posterior border of the cricoid.
 - d. **The Epiglottis**—thin flexible cover to glottis during swallowing.
- 2 **The Vocal Cords**—elastic bands embedded in mucous membrane.
Variations in their length and tension alter their frequency.
3. **The Glottis**—the chink between the vocal cords.
4. **Muscles**—to control vocal cords. In two sets :—
 - a. Those to open and close glottis—volume control.
 - b. Those to regulate tension and length of cords—frequency control.

The range of the human voice is about two and a half octaves.

CHAPTER XXXVIII

THE ENDOCRINE ORGANS

MANY glands are supplied with ducts by which their secretions or excretions are carried away. In these cases it is an easy matter to collect a sample of the fluid secreted, and then to examine its chemical and physical properties. There are, however, many organs clearly glandular whose secretion is not passed out *via* a series of ducts. In these cases the secretion, made from the capillary blood supply to the tissues, is immediately handed out to the venous blood or lymph which issues from the organ. Such glands are known as internally secreting or **endocrine** (Gr. *endon*, within ; *krino*, I secrete).

Those organs, like the salivary glands which have ducts to carry off the secretion, are similarly called **exocrine** (Gr. *ex*, out). In some instances we find glands which partake of the nature of both, such as the liver and pancreas. The former produces bile, secreted into the bile capillaries and ultimately poured into the duodenum by the bile duct. It also passes glucose and urea directly into the hepatic veins. From the above the idea gradually arose that the endocrine organs gave rise to certain chemical products that entered the circulation, and were carried to other organs which made use of them. Experimental investigation was carried out by the obvious method of making extracts of the glands in question. The effect of these extracts upon normal animals and man was noted, and it soon became apparent that these effects were due to the presence of definite chemical substances in the extracts. The special active principles produced by the endocrine organs were collectively known as **autacoids** (Gr. *autos*, self ; *akos*, a remedy). Some autacoids, indeed most of them, were found to stimulate the activity of other organs, and were therefore called **hormones** (Gr. *hormao*, I excite), while others slowed down or inhibited functional activity. These latter are called **chalones** (Gr. *chalaoo*, I loosen). Usually, however, all are spoken of as hormones irrespective of the nature of their activity. The

essential feature of an endocrine organ is that it exercises a chemical control on other organs.

The following is a list of the organs generally considered as endocrine :—The thyroid, with the parathyroids, the islet tissue of the pancreas, the ovaries (corpora lutea, and interstitial tissue), the testicular interstitial tissue, the adrenals (cortex and medulla), the pituitary (anterior and posterior lobes), the thymus, and perhaps the pineal body.

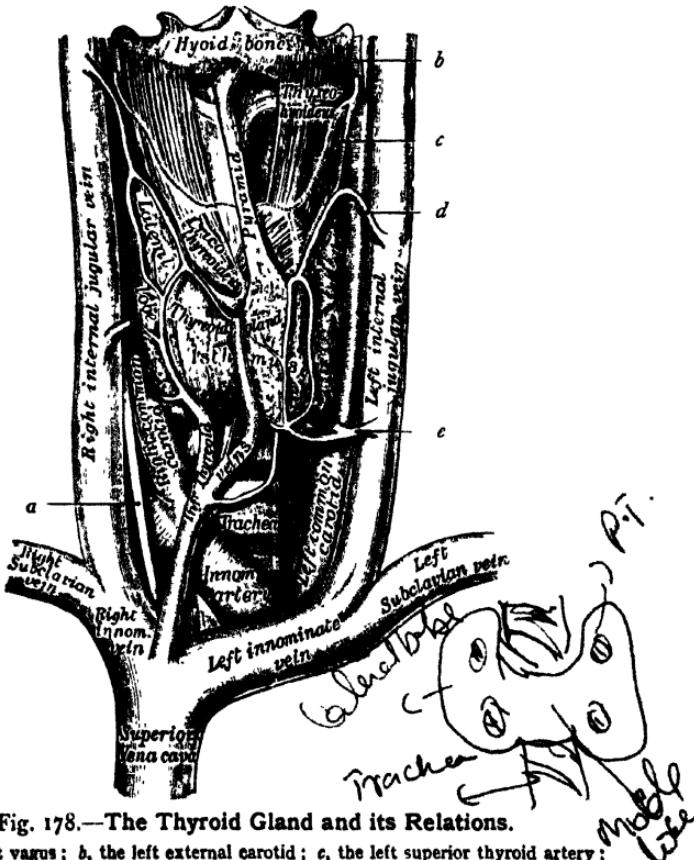


Fig. 178.—The Thyroid Gland and its Relations.

a, the right vagus ; b, the left external carotid ; c, the left superior thyroid artery ; d, the left superior thyroid vein ; e, the middle thyroid vein.

1. **THE THYROID GLAND** consists of two lateral lobes united by a middle lobe. The lobes lie one each side of the larynx and upper part of the trachea. Histologically the gland is a collection of closed vesicles, lined by cubical epithelium

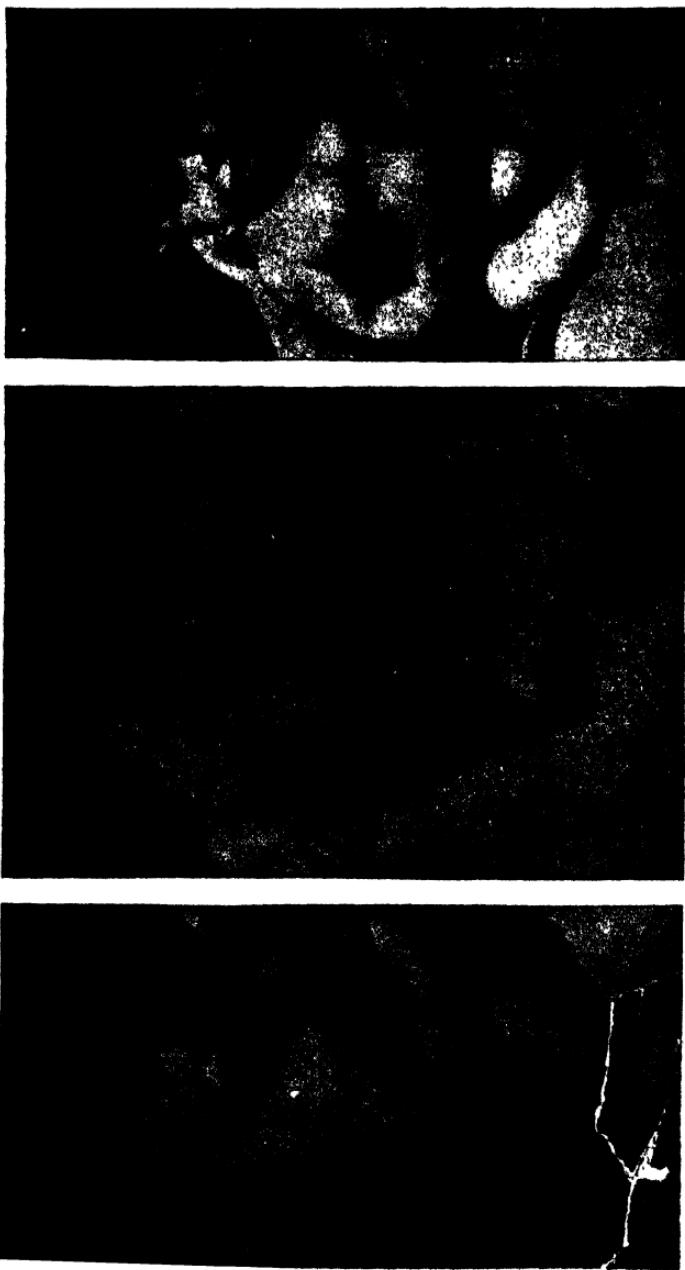


Fig. 179.—The Effects of Thyroid Insufficiency.

Left—a child showing marked thyroid deficiency, producing physical deformities and mental deficiency. Centre—same child after some months' treatment with (Sher's) thyroid. Right—same child a year later, showing return of symptoms, after its parents had refused continuance of treatment. (Reproduced by permission from the *Journal of Heredity*.)

and secreting a colloidal substance. On examination this colloid contains an active principle (autacoid) called **thyroxine**. By experiment on man and animals it has been found that its effects are to increase metabolism, i.e. the rate at which the body processes go on. If there is a deficient action of the gland in childhood, the condition known as **cretinism** is produced. An analogous deficiency in adult life is known as **myxœdema**. Both these conditions can be cured by giving **thyroxine** or feeding on thyroid glands. It should be remarked that **thyroxine** is the only hormone which can be taken by the mouth—all the others undergoing alimentary digestion. Conversely, if there is over activity of the gland the condition of **exophthalmic goitre** is produced. However, in this case there is reason to believe that mere excess of **thyroxine** does not explain all the symptoms, particularly the exophthalmos, i.e. the bulging of the eyeballs. The condition is greatly relieved by surgical removal of a portion of the gland.

Thyroxine contains iodine, which seems to be essential to the activity of the gland. Any deficiency in the supply of this element may lead to a swelling of the thyroid gland known as a **goitre**. The condition is prevalent in certain chalky districts, and may be prevented by the giving of iodine. **Goitre** refers to any enlargement of the thyroid gland, with no functional disturbance.

2. **THE PARATHYROIDS** are four small brownish-red bodies situated behind and embedded in the thyroid gland, two superior and two inferior. Though so closely associated anatomically with the thyroid, they have no relation to it, but are concerned with the metabolism of calcium. If removed, the blood calcium (normally 10 mgms. per 100 c.c. blood) falls



Fig. 180.—Case of Exophthalmic Goitre.

(*The Endocrine Organs*, Schäfer.)

and the condition of **tetany** occurs—tremors, muscular cramps, spasm of the glottis and convulsions. If excessive doses of the gland extract are given the blood calcium rises and there is depression of the nervous system. The bones are to be regarded as storehouses of calcium which can be drawn upon under the influence of the parathyroids, when required.

3. **THE THYMUS** lies partly in the neck and partly in the thorax, behind the sternum and in front of the aortic arch. The gland grows during childhood, but degenerates after puberty. It seems to have some relation to sexual growth, holding it

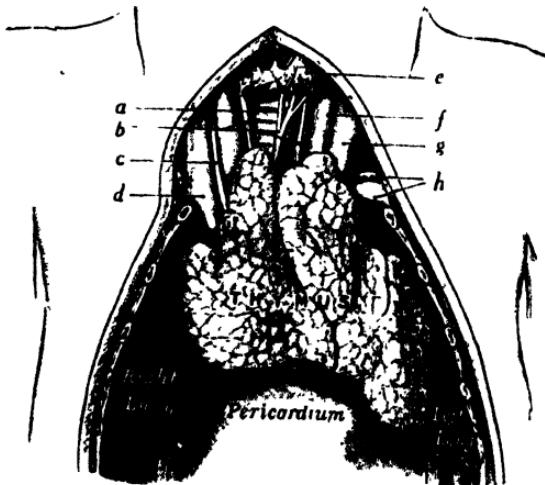


Fig. 181.—The Thymus (full-time foetus).

a, trachea ; *b*, thyroid veins ; *c*, right vagus ; *d*, sup. vena cava ; *e*, thyroid gland ; *f*, left common carotid artery ; *g*, left int. jugular vein ; *h*, left subclavian vessels.

in check until sufficient skeletal growth is attained. Castration causes the thymus to persist, while removal of the thymus accelerates sexual development. It contains a large amount of lymphoid tissue. Removal of the gland, or extract of the gland, produces no effect. Perhaps it is not an endocrine organ.

Status lymphaticus is a condition in which the thymus persists in adolescents, together with a general increase of lymphoid tissue all over the body. These people are of poor physique, mentally dull, and readily die under an anaesthetic for no known reason. It is, however, impossible to diagnose the condition beforehand.

4. THE PITUITARY GLAND lies in a hollow in the sphenoid bone. Like the adrenals it is in two parts, which are developmentally and functionally different. Its anterior portion comes as an outgrowth from the mouth in the foetal state, and the posterior lobe is a down-growth from the brain.

(a) The anterior lobe has many functions. It controls skeletal growth, metabolism, and the sex organs. If the secretion is deficient (hypopituitarism) there is a failure in development—sexually, mentally and skeletally, known as **infantilism**. If there is overdevelopment, then we have the condition of hyperpituitarism produced. If this occurs before

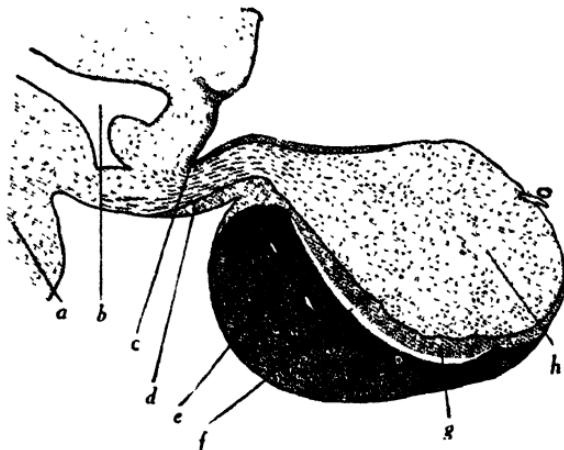


Fig. 182.—Medial Section through the Pituitary Gland.

a, optic chiasma; b, 3rd ventricle; c, d, g, portions of pars intermedia; e, anterior lobe; f, interlobular cleft; h, posterior lobe.

puberty, i.e. before the union of the epiphyses, then **gigantism** (increased growth in the limb bones) and increased sexual development results, while if after puberty, the condition only affects the other bones, producing what is called **acromegaly**.

Another anterior pituitary hormone possibly stimulates the thyroid, while a third stimulates ovulation.

(b) The posterior lobe really consists of two portions—the *posterior intermedia*, which gives rise to the secretions, and the *posterior nervosa*. Extracts of the posterior lobe seem to produce many different results. Whether each is due to its own particular active principle is not yet settled. The chief effects produced by an injection into man (or animal) are:—

1. Increase of blood sugar (glucose) leading to glycosuria.
It antagonises the action of insulin.
2. Vaso-pressor effect, *i.e.* constriction of the capillaries and arterioles—which therefore raises the blood pressure.
3. Constriction of the muscle of the gut and bladder.
4. Decreases the urinary output in man, *i.e.* is antidiuretic.
It helps in the regulation of the water content of the body.
5. Oxytocic effect, *i.e.* contraction of uterus (pregnant or not).
6. Melanophore dilation in the amphibian skin.

The above list merely states the results of giving extracts. It is not to be inferred that these represent the normal functions

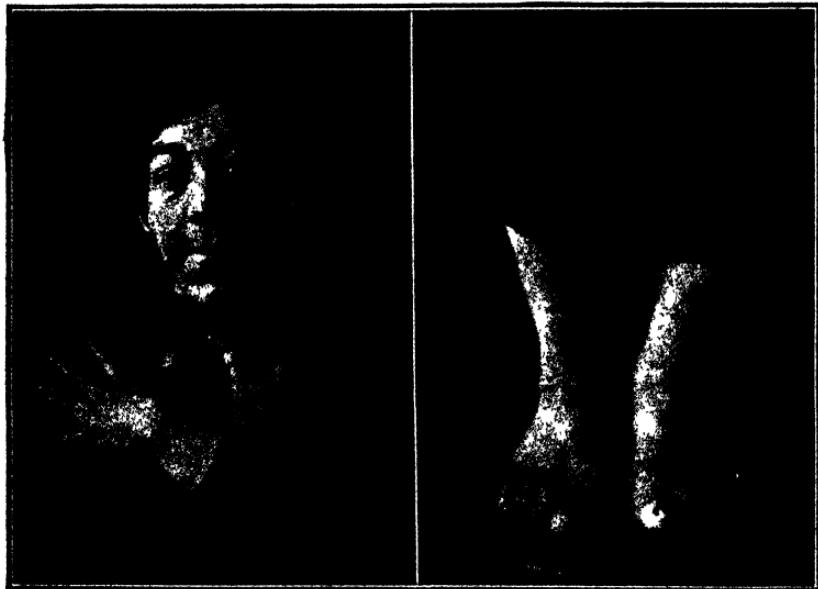


Fig. 183.—A case of Acromegaly.

The X-rays show enlargement of the bony cavity within which lies the pituitary body.
Note the thickening of the bones of the hands and feet. (Photos kindly lent by Dr. R. Hutchison.)

of the posterior lobe. It has some relation to carbohydrate metabolism, it controls urinary flow, and has something to do with the onset of labour. Therapeutically, however, the oxytocic and the antidiuretic effects are of great value. The former is useful in parturition, and the latter in the treatment of diabetes insipidus, where large quantities of urine are passed daily (up to 10 litres).

5. THE SUPRARENAL (or ADRENAL) GLANDS are two small bodies of yellowish colour behind the peritoneum, one lying just above each kidney. On slicing one open, it is seen to consist of two portions, an outer yellowish part (the cortex), and a thin red inner part (the medulla). Corresponding to this obvious naked eye difference, there is also a difference in their developmental origin.

(a) The **cortex** is related to the gonads (testes and ovaries). Its function is unknown. Tumours of the cortex lead to premature sexual development in the young, before puberty, and in the adult female to the appearance of masculine

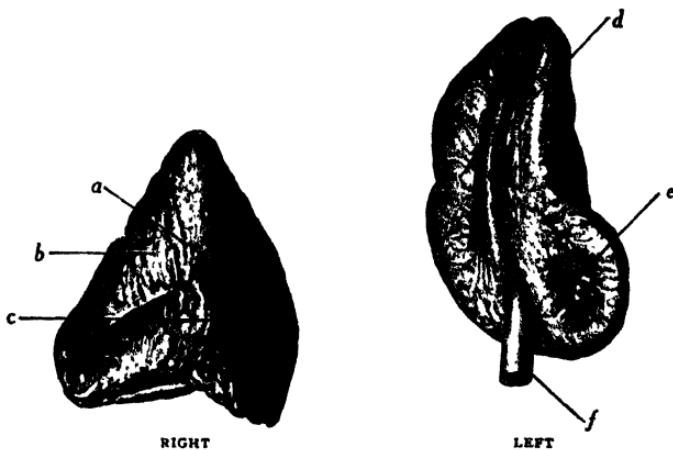


Fig. 184.—The Suprarenal Glands (anterior view).

a, right suprarenal vein; b, area facing liver; c, area in contact with inf. vena cava; d, area facing stomach; e, pancreatic area; f, left suprarenal vein.

characters. Removal of the cortex invariably brings about death in a short time.

(b) The **medulla** is related to the sympathetic system. It consists of a network of connective tissue fibres, capillary blood spaces or sinusoids, a plexus of nerve fibres and ganglia, and masses of granular cells. These latter secrete a chemical substance, *adrenaline*, which is directly absorbed into the blood-stream. In the normal way it does not seem to produce any effect, and it is only in times of stress or emergency (rage, cold, anxiety, fever) that it is secreted in any demonstrable amount.

Administered therapeutically, as an intravenous or subcutaneous injection, the effects are chiefly on the circulation.

The blood pressure rises a little because of the intense vasoconstriction, and this reflexly acts on the vagal centre in the medulla producing a slowing which more than counteracts the peripheral stimulating effect on the heart. The vaso-constriction is mainly on the splanchnic area and cutaneous vessels, while the coronaries and muscle vessels are dilated. Other effects are the inhibition of peristalsis with contraction of the sphincters, relaxation of the bronchi, dilation of the pupil, melanophore contraction in amphibia, relaxation of the uterus, and mobilisation of glycogen (*i.e.* its conversion to glucose) producing a hyperglycæmia and a glycosuria.

In short, adrenaline may be said to stimulate all structures innervated by the sympathetic system, with the exception of the sweat glands.

Addison's disease is related to the adrenals, associated with muscular weakness, wasting, low blood pressure, vomiting and bronzing of the skin. Its cause is unknown. Extracts of the cortex, known as *cortin*, are said to bring about a (partial) recovery.

6. THE "ISLETS" OF THE PANCREAS secrete a hormone known as *insulin*, which controls carbohydrate metabolism, and, through it, fat metabolism also. This it does by enabling the tissues to use glucose as a source of energy, and the liver and muscles to store glucose as glycogen. By so doing the conversion of protein to glucose, which occurs in diabetes, is made unnecessary.

The normal amount of sugar in the blood is about 0.10 per cent., which on rising to 0.18 per cent. is excreted by the kidneys, producing a *glycosuria*. In diabetes mellitus (or experimentally by removal of the pancreas) sugar cannot be utilised by the tissues nor stored as glycogen, owing to a deficiency in insulin. There is produced a condition of *hyperglycæmia* and *glycosuria*. These effects are remedied by the giving of insulin. It has no action if given by the mouth, and must be injected subcutaneously. The *hyperglycæmia* causes a corresponding increase in the amount of urine excreted, *i.e.* there is produced a *polyuria* as well as a *glycosuria*. *Hyperglycæmia* may also be brought about by hyperthyroidism, and by hyperpituitarism. A normal person should be able to eat at least 100 grams of glucose without a resulting *glycosuria*, and even if more were taken it would but lead to nausea and vomiting. In the case of the diabetic owing to the faulty combustion of carbohydrates, fats are also incompletely oxidised,

leading to the excretion of certain fatty acids—a condition known as *ketosis*.

If the blood sugar falls below 0·07 per cent. (*e.g.* by the injection of insulin) a condition of *hypoglycaemia* is produced. The symptoms are a rapid pulse, tremors, anxiety, faintness, sweating, and often unconsciousness. These cease on the administration of glucose by the mouth, or by the injection of adrenaline or posterior pituitary, for these latter hormones stimulate the liver to mobilise its glycogen stores, so as to keep the blood sugar at a constant level.

SUMMARY

THE ENDOCRINE OR INTERNALLY SECRETING ORGANS.

No ducts—direct secretion into lymph or blood-stream.

1. **The thyroid**—secretes thyroxine which accelerates metabolic rate.
Deficiency in the child leads to cretinism, in the adult to myxoedema.
Excess leads to exophthalmic goitre.
2. **The parathyroids**—embedded in and behind thyroid (2 each side).
Concerned with calcium metabolism—normally 10 mgms. per cent.
Deficiency produces the condition tetany.
3. **The thymus**—lies between the sternum and aortic arch.
Grows in childhood, degenerates after puberty→sexual growth?
Castration causes its persistence, yet no effect if removed.
4. **The pituitary gland**—lies in a hollow in the sphenoid bone.
Consists of two portions developmentally and functionally different.
 - a. *Anterior lobe*—related to skeletal and sexual growth (ovulation).
Overgrowth before puberty produces gigantism, after puberty acromegaly. Deficient growth leads to infantilism.
 - b. *Posterior lobe*—produces many different results:—
Constricts arterioles and capillaries, decreases urinary output.
Contracts the uterus, produces glycosuria, antagonises insulin.
5. **The suprarenal glands**—lie one just above each kidney.
 - a. Cortex—related to metabolism and sexual growth.
 - b. Medulla—related to sympathetic system. Secretes adrenaline.
6. **The "islets" of the pancreas**—produce insulin, which enables the tissues to utilise glucose, the liver and muscles to store glucose as glycogen.

CHAPTER XXXIX

HISTOLOGY—THE SIMPLE TISSUES

HISTOLOGY is the study of the microscopic anatomy of animal or vegetable structures.

If a thin section of a plant or animal is examined microscopically it will be seen to be composed of a vast number of separate entities known as "cells." Each cell consists of a mixture of complex chemical substances in a "living" condition, called **protoplasm**, containing within it a specialised portion, the **nucleus**. In plants there is a demonstrable cell wall separating each cell from the other. Such, however, is not the case with animal cells. Protoplasm is very variable in composition. It consists, on analysis (though what is analysed is really only *dead* protoplasm), of a mixture of complex proteins. The living matter which constitutes the nucleus is **nucleoplasm**, and that in the rest of the cell **cytoplasm**.

THE CHARACTERISTICS OF A CELL.—In the general description which follows it must be understood that no one cell will necessarily possess all the characters here described. Some cells may exaggerate certain characters, while others may not have them at all. All cells are built on the same morphological plan, in spite of a great diversity in form and function. ✓

1. The protoplasm may always be divided into two parts :—
 - (a) The **cytoplasm**—the general cell protoplasm, consisting of a vast collection of proteins of varying composition. It varies greatly in extent and appearance in different cells.
 - (b) The **nucleoplasm**—that of an obviously specialised more or less centralised structure or structures, the nucleus (or nuclei), for there may be more than one. It seems to have a well-defined cell wall.
2. Embedded within the cytoplasm are various structures of foreign material, collectively known as paraplasma, and may have been formed in the cell, or taken in from without. They are :—
 - (a) **Granules**—there are many varieties, the chief being :—Pigment, *i.e.* coloured particles, never found in the nucleus.

Pre-secretory—such as ptyalinogen and mucinogen.

Storage products—glycogen, iron, fat globules, foreign bodies such as bacteria, parasites.

Vacuoles—containing a watery fluid.

(b) **Centrosomes**—near the nucleus, consisting of a minute spot (centrosome, or attraction sphere). They appear to preside over the reproduction of the cell. In some cells they are multiple, as in leucocytes and giant marrow cells.

(c) **Chondriosomes** (mitochondria)—other granules found around the nucleus. When a cell divides they are distributed among the two daughter cells. They appear to preside over the manufacture of storage or excretory products of the cell.

3. Embedded in the nucleus are :—

(a) One or more **nucleoli**—small spherical highly refractile bodies. They are very characteristic of nerve cells, cartilage cells and ova. The nucleolus disappears during cell division. It is possibly concerned with the storage and elaboration of chromatin.

(b) **Chromatin**—a delicate network of fibrils knotted at their junctions. It consists of nuclei acid, and is well stained with basic dyes (methylene blue, saffranin, haematoxylin), hence its name. It is very evident in young cells.

SHAPE OF CELLS AND THEIR NUCLEI.—These vary considerably, and are of some importance.

(a) **The cell** may have almost any shape—flat, polyhedral, cylindrical, cuboid, stellate, spherical or completely irregular. As regards the meaning of this great variety, it may be partly due in some cases to pressure (especially the polyhedral shapes), but in general it is adaptation. The pulmonary alveolar cells are flat for the more rapid diffusion of O₂ and CO₂ across them ; the columnar cells of ducts for palisading ; the stellate cells of the nervous system for the attachment of its many fine processes, and so on.

(b) **The nucleus** is usually of a globular shape, though there are some important exceptions, as the rod-shaped (better cylindrical) nuclei of plain muscle. In other cases it may be ovoid, annular, bilobed or multilobed. The size varies ; some are so large as to nearly fill the cell, others are still quite large though not occupying the whole of the cell, and yet others are very small. It is absolutely essential to the life of the cell, controlling its nutrition and subdivision. The shape of the nucleus is sometimes of great importance in the differentiation of structures.

THE SIZE OF CELLS.—The unit of histological measurement is the micron, μ , where one μ is 0.001 mm. Cells vary from 7μ to 20μ in diameter. The relative size is of importance, as also the nucleus, in differentiation.

It is convenient to remember that the size of an average red corpuscle is about 7.2μ , a streptococcus about 1μ , and the ovum 200μ , easily the largest cell in the human body, in fact, just about visible as the merest speck to the naked eye.

PROPERTIES OF A LIVING CELL.—The following is a list of the physiological properties or functions of a living cell :—

1. **Irritability or sensitivity.** This means that it has the capacity to receive and make response to its appropriate stimuli. These stimuli are of many sorts, such as gravitational, mechanical, thermal, electrical, chemical, solar and photic.

2. **Metabolism**, the series of chemical changes whereby a cell can convert nutritive material into the complex compounds of protoplasm, and use them for the performance of specific functions. This is presided over by the nucleus. Associated with this is its power to give out (excrete) waste material.

3. **Motility**—resulting from the response to stimuli. This motion may be of various types, such as ciliary, amœboid, muscular (contractile).

4. **Reproduction or cell multiplication.** Science does not accept the idea that cells may arise spontaneously, but that every cell has its origin in a parent cell, or otherwise expressed as an aphorism *omnis cellula e cellua*. The division of cells may take place in one of two ways :—

(a) **Amitosis**, that is, simple splitting of the nucleus into two, followed by similar cytoplasmic division.

(b) **Karyokinesis or mitosis**, a more elaborate method, and much the more common.

A TISSUE is a collection of similarly specialised cells, and the products (if any) laid down by them. This specialisation is for the performance of some particular function, such as secretion, contraction, absorption, etc. In some cases the cell predominates (liver, kidney), while in other cases it is very much hidden by the products of its own activity, as in tendon, bone, cartilage and fat.

CLASSIFICATION OF TISSUES.—This may be done on several different bases—function, origin, staining characters, etc. On a careful examination of these modes it will be found that no one is entirely satisfactory, there being a great deal of

overlap, or the classification of two tissues together that are clearly unrelated, or the placing of the same tissue in two categories. As a result of this unsatisfactory method, and partly as a matter of history, we adopt a classification which is rather a matter of practical convenience than one based on a strictly logical plan.

1. **Epithelial**—that which covers the body, and lines its various cavities. It serves for protection, secretion, excretion and as receptor organs for the absorption of appropriate stimuli.

2. **Connective**—that which connects and supports all the other tissues, the intercellular element predominating. The cellular element is usually scanty.

3. **Muscular**—a contractile tissue bringing about movements of the body, its limbs, or some of the viscera.

4. **Nervous**—is that which co-ordinates all the others.

I. **EPITHELIUM**.—The term “epithelium” is applied to the cellular tissue that, continuous with the **epidermis**, lines the entire length of the digestive tube, composes the glands and their ducts ; also to the membranes that form the linings of the blood-vessels, lymphatics, and serous cavities ; the respiratory passages ; the sensory surfaces of the mouth, nose, eyes and ears ; the cavities of the brain ; the central canal of the spinal cord ; and those structures derived from skin—teeth, nails and hairs.

CLASSIFICATION OF EPITHELIUM.—In structure, epithelium consists of cells of various shapes. Epithelia are classified partly on the basis of shape and on the number of layers of cells.

1. **Endothelium**.—The epithelial lining of the heart, blood-vessels, pulmonary alveoli, lymphatics and all serous cavities, consists of very flat squamous cells, only arranged in a single layer, and to this the special term **endothelium** is more commonly applied.

2. **Stratified Epithelium**.—Sometimes the cells are arranged in several superimposed layers known as **stratified epithelium**, as, for instance, the epidermis.

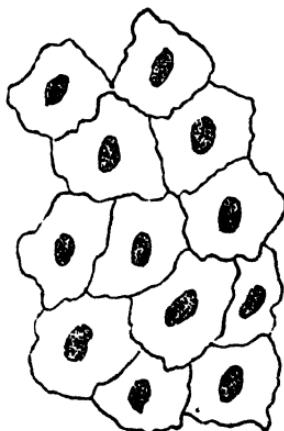


Fig. 185.—**Squamous Epithelium**—from the Peritoneum. ($\times 400$.)

Those epithelial structures which consist of flat scale-like cells are known as **squamous**, or **tesselated epithelia**. In these the cells are cemented together by some kind of **intercellular substance**. The epidermis is of this character; and it will be remembered that, in this instance, there are numerous superimposed layers of cells.



Fig. 186.—Stratified Squamous Epithelium—from the Oesophagus (human).

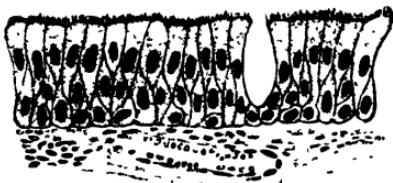


Fig. 187.—Columnar Ciliated Epithelium—from the Trachea.
Note the ruptured goblet cell.

3. Columnar Epithelium.—The mucous membrane of the stomach, the intestine, the ducts of all glands, the prostate and vas deferens, are lined by a layer of elongated cylindrical or prismatic cells, arranged with their long axes at right angles to the free surface. Such cells form what is called columnar epithelium, and usually exist as a single regular layer. These cells are either absorptive or secretive.

4. Ciliated Epithelium.—The free surfaces of the epithelial cells of certain parts are clothed with minute hair-like processes called **cilia**, there being from ten to thirty attached to each individual cell. These cilia are perpetually in motion, lashing to and fro in such a manner that all those of the same surface tend to propel any particles which come into contact with them in one direction. Thus, if the ciliated epithelium in question happens to line a cavity (*e.g.* trachea, fallopian tube, epididymis), all foreign matter resting on the surface is urged on towards the orifice of the cavity. The cells of ciliated epithelium are generally cylindrical or columnar in form. This kind of epithelium lines all the air passages of the lungs, and the respiratory tracts of the nostrils; also the cavities of the brain, the

central canal of the spinal cord, and some portions of the genital passages of both sexes (fig. 187).

5. **Cubical Epithelium.**—A slight modification of this is **cubical epithelium**, the cells being about as tall as they are wide. This type is found in the pancreatic ducts, thyroid and parts of the kidney tubules (fig. 188).

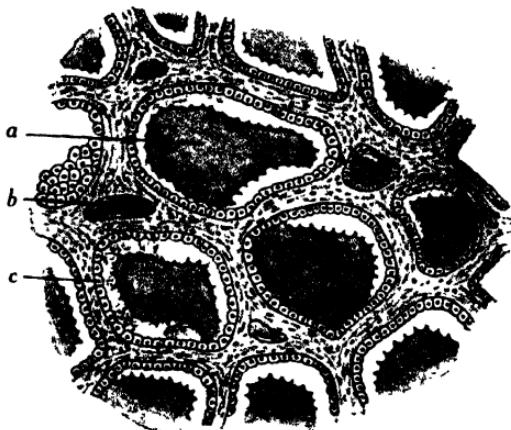


Fig. 188.—Cubical Epithelium—from the Thyroid Gland.

a, masses of shrunken colloidal matter within the alveoli; *b*, lymphatic vessel; *c*, cubical epithelium forming the alveolar wall.

6. **Glandular Epithelium.**—In the linings of the ducts and cavities of glands we meet with cells, morphologically columnar, but which have often become polygonal by their mutual pressure. Since they are the active agents by which the various secretions are prepared from the blood that circulates in the neighbouring capillaries, the epithelial tissue which they form is often spoken of as **secreting** or **glandular epithelium**. Examples of this variety may be seen in the peptic glands of the stomach, in the tubules of the kidney, in the salivary glands, liver and pancreas.

7. **Transitional Epithelium** consists of from two to about five layers in depth. It is found lining the urinary passages from the pelvis of the kidney to the prostatic portion of the urethra inclusive.

8. **Neuro-epithelium** is a modification of epithelium which constitutes the receptor organs. Thus we have the rod and cones in the retina, the cells of the taste buds, the olfactory cells,

the cells of the organ of Corti, and those in the crista^e and macula^e, and the numerous touch corpuscles in the skin.



Fig. 189.—Transitional Epithelium—from the Urinary Bladder.

This epithelium is usually three to five layers deep. Outside it are to be seen some plain muscle fibres.

THE FUNCTIONS OF EPITHELIUM are the protection of other tissues, the production of motion, the absorption of digested material or the preparation of a secretion ; or two of these functions may be performed by one and the same epithelial lining. Some epithelial cells have also a sensory function, such as those which line the olfactory region of the nose, or form the taste buds, and those which form the sensory surface (retina) of the eyeball, as mentioned in the preceding paragraph. Hence the more appropriate term *neuro-epithelium*.

Certain structures are apparently quite different from epithelium, but on examination are found to be merely modifications of it, such as the hair, nails and enamel.

II. CONNECTIVE TISSUE is, as its name suggests, that which supports and connects the other tissues of the body. It is found in all parts of the body. There are many apparently very different varieties, but it will be found that microscopically and chemically these are similar. In all cases they have a common similarity of structure, viz. a basis or matrix in which are embedded cells and fibres.

- (a) The cells, from which the matrix and fibres are derived.
 - (b) The matrix may be plasma, cartilage or mucinous.
 - (c) The fibres may be relatively absent or very abundant.
- The proportion of these components is liable to variation.

1. **Embryonic connective tissue** consists of many-branched cells, as seen in the umbilical cord and dental pulp.

2. **Areolar tissue** is a rather loose tissue connecting the various parts of organs, or forming their framework. It consists of fine interlacing threads with comparatively wide meshes or areolæ. In these spaces may be found various sorts of cells. If the fibres are carefully examined they are seen to be of two sorts. One variety consists of bundles of relatively coarse interlacing fibres. Others occur singly, are much finer, and join with others. These are respectively known as white



Fig. 190.—Bundles of White Fibres, partially teased out.
Note their wavy character.

fibres and elastic fibres. If there is an unusual number of fat cells in these areolæ, then the tissue is designated as **adipose tissue**, such as one may find in the yellow marrow of bones, around the kidneys and heart, and in the mesentery. Sometimes we find the meshes occupied by white cells (lymph corpuscles), and then the tissue is called **lymphoid** or **adenoid tissue**. The lymph glands and tonsils are good illustrations.

3. **White fibrous tissue** is almost entirely composed of bundles of white fibres, usually running in some definite direction. The spaces between the bundles are filled with flattened cells lying in rows and by areolar tissue with its blood-vessels and lymphatics. It helps to form ligaments and tendons. Also it

forms tough membranes such as the dura mater, the pericardium, and the fibrous coats of organs, such as those of the kidney and lymph glands.

4. **Yellow elastic tissue** has a preponderance of yellow elastic fibres. It may be either of the straight variety such as one meets with in the lungs and laryngeal cartilages, or of the corrugated laminar variety found in the walls of the blood-vessels.

5. **Cartilage** and **bone** are also varieties of connective tissue.

CARTILAGE or gristle is bluish-white or yellow in colour according to its composition. It is very elastic, and performs various functions in the body. Thus it helps to form the thorax (elastic for respiratory purposes), it keeps open tubes such as the trachea and bronchi, and it is a preliminary to the formation of bone. Like other forms of connective tissue it has a matrix, cells, and sometimes fibres. The matrix is non-vascular, so that nutrition must be *via* the lymph. Cartilage cells are somewhat triangular in shape, with rounded corners, and usually arranged in pairs.

The classification of cartilage is based on the presence or absence of fibres in the matrix.

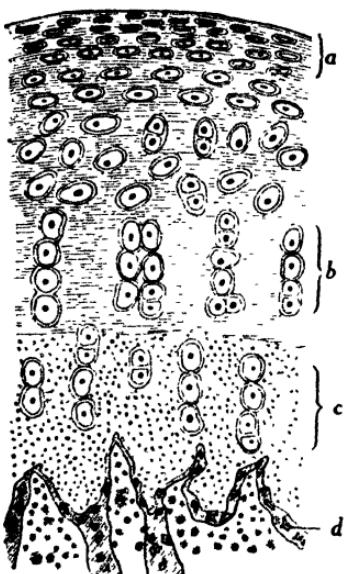
Fig. 191.—Articular Cartilage—Vertical Section of Growing End of a Bone.

a, superficial flattened cartilage cells; b, vertical rows of cells; c, calcified matrix; d, cancellous bone.

(a) **Hyaline cartilage** has no fibres (Gr *hualos*, clear). It forms the articulating ends of bones in the respiratory tract (nose, larynx, trachea and bronchi), the foetal cartilage from which bone is afterwards formed, and costal cartilage.

(b) **White fibro-cartilage** has its matrix permeated with white fibres. It is found interposed between the bones in all small joints (*e.g.* wrist) and lining articular cavities such as the glenoid cavity and the acetabulum. It forms the semilunar cartilages of the knee-joint—which so often get displaced in those who play football.

(c) **Yellow or elastic fibro-cartilage** has elastic fibres



in its matrix. It is found where great flexibility is required, as in the epiglottis, Eustachian tube and pinna.

Perichondrium is a connective-tissue fibrous covering to cartilage, which serves for its nutrition. It is continuous with the periosteum.

Synovial membranes are thin connective-tissue coverings across some joints, but not over the articulating areas. They secrete a little fluid for the lubrication of the joint.

BONE is calcified cartilage in most cases (bones of the limbs), and calcified connective tissue in the rest (skull bones—sides and roof). Its general naked-eye appearance has already been explained—the

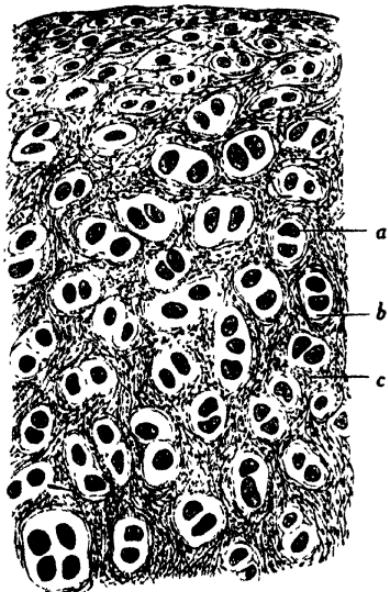


Fig. 192.—Elastic Fibro-cartilage, from the Epiglottis of a Cat.

a, is a cartilage cell; b, is the clear matrix around the cell; c, is the elastic fibres.

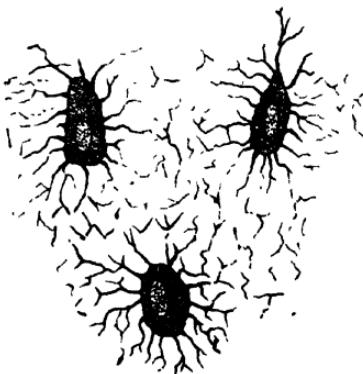


Fig. 193.—Bone Cells contained within the Lacunæ.

Note that their branches pass into the canaliculi which are all in communication with each other and eventually with a Haversian canal.

compact bone of the shaft, the central medullary cavity, and the cancellous bone at the extremities.

In order to study the minute structure of bone it will be necessary to cut a very thin slice from the compact tissue, and grind this down till it is semi-transparent. If the cutting be made transversely, it will show, under the microscope, cross sections of minute canals, called **Haversian canals** from Havers, who first discovered them. These canals vary in size, the average diameter being about $\frac{1}{60}$ of an inch. The Haversian canals are surrounded by small, irregular spaces called **lacunæ** (Lat., *cavities*), arranged in concentric circles, and so giving the bone a laminated appearance. The lacunæ

communicate with each other, and with the Haversian canals, by means of very minute **canalliculi** which radiate from them in all directions. In life these lacunæ are occupied each by a **bone cell**, whose processes ramify among the canalliculi. They somewhat resemble connective-tissue cells—for bone is really a connective tissue whose ground substance (matrix) is impregnated with calcium salts.

If the section of bone be made longitudinally instead of transversely, then the Haversian canals will be opened along their length, as they run in the direction of the long axis of the bone. They will then be seen to branch and communicate with one another (fig. 194).

The Haversian canals are well supplied with blood-vessels. The canalliculi and lacunæ take up the nutrient matter from the blood, and distribute it throughout the bone.

Bone is developed in one of two ways :—

(a) **In membrane**—that is, the original embryonic connective-tissue outline of the future bone becomes calcified. This occurs in the thin bones forming the front and sides of the skull—parietal and frontal bones. They consist of two layers of compact bone with cancellous bone between.

(b) **In cartilage**—that is, the embryonic structures become first cartilaginous (of the hyaline variety) and then osseous,

Fig. 194.—Longitudinal Section of Bone. ($\times 100$.)

a, Haversian canals; b, c, lacunæ.

i.e. converted to true bone. This is found in all the rest of the bones of the skeleton.

III. MUSCULAR TISSUE.—There is a distinct difference between the structure of voluntary and involuntary muscle, associated with corresponding differences in physiological behaviour.

We will first study the structure of **voluntary muscles**. As already stated, we include under this term all those muscles



which may be set in motion by an effort of the will. If we remove the skin from the leg of a rabbit, we at once expose several of these voluntary muscles, each of which is connected with two separate bones. Then if we trace one of these muscles to one of its ends—its origin or its insertion—we notice that it is connected with the bone by means of a tendon. Note that the muscles are surrounded by a sheath, composed of a very thin and transparent membrane, called *epimysium*.

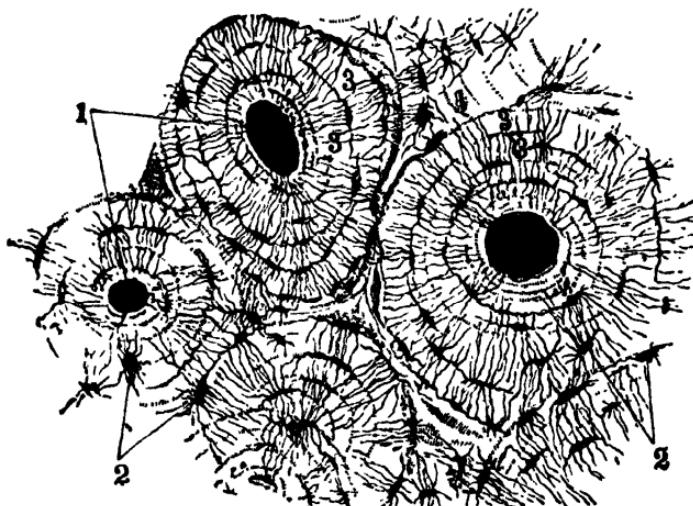


Fig. 195.—Transverse Section of the Compact Bone. ($\times 150$).
1, Haversian canals; 2, lacunæ; 3, laminæ.

Now let the leg of the rabbit be boiled till the flesh is easily torn asunder ; and, by means of needle-points, we may then "tease out" the flesh in such a manner as to show that each muscle is composed of **bundles of fibres**.

As a further, and perhaps a better, illustration of this last point, take a small portion of a very large muscle, such as one of those which form the fleshy portion of a "leg of beef." Let this also be boiled till its fibres may easily be separated by needle-points. We shall now see distinctly that not only is the muscle composed of bundles of fibres, but that each *bundle* is made up of still **smaller bundles**, each of which is distinctly visible to the naked eye. These *smaller bundles* are called *fasciculi* (Lat. *fasciculus*, a little bundle) ; and the fineness or coarseness of a muscle depends on the relative sizes of these small bundles of

fibres. Thus, in the powerful muscles of the leg, the fasciculi are much larger than in the softer muscles of the cheeks.

If it is desired to study the structure more minutely, it will be necessary to take a very small portion of muscle, and, after teasing it out till it is so fine as to be almost invisible to the naked eye, examine it with the help of a good microscope.

In this way we learn that the fasciculi are composed of fibres, each one of which is not more than $\frac{1}{50}$ of an inch in diameter on an average, and about 1 inch in length ; and that these fibres are composed of still smaller fibres or **fibrils** (Lat. *fibrilla*, a little fibre).



Fig. 196.—Two Voluntary Muscle Fibres. ($\times 250$.)

Note the cross striations and two nuclei lying just under the sarcolemma.



Fig. 197.—Transverse Section of Four Voluntary Fibres. ($\times 255$.)

The fibrillar nature of each fibre is well seen, and also the peripherally situated nuclei.

When the fibrils are examined under a high magnifying power, they are seen to consist of little disc-shaped bodies, united in such a manner as to produce transverse markings. It is on this account that voluntary muscle is often called **striped** or **striated muscle**.

Every fibre in a voluntary muscle is enclosed in a sheath of connective tissue called **sarcolemma** (Gr. *sarr*, flesh ; and *lemma*, a husk). This is a very thin, transparent, and comparatively tough membrane, which will sometimes remain entire after the enclosed fibrils have been ruptured by stretching or twisting. The nuclei lie just under the sarcolemma and are of oval shape.

Involuntary muscle is non-striated (except cardiac muscle), because it does not present transverse markings when examined under the microscope, as does voluntary muscle. Involuntary muscle is often made up of bundles of fibres ; but the fibres, instead of being of uniform diameter throughout,

are composed of elongated cells which are generally pointed at their ends. These fibres have no true sarcolemma. Their nuclei are rod-shaped and lie centrally within the substance of the fibre.



Fig. 198 Involuntary Muscular Fibres from Human Blood-vessels.

Note the rod-shaped centrally placed nuclei and the fusiform cells



Fig. 199 Longitudinal Section of Human Cardiac Muscle.

Note the centrally placed nuclei, the faint transverse striations, and the irregular quadrilateral cells

The muscular fibres of the heart differ remarkably from those of involuntary muscles in general, as they are faintly striated transversely, like those of the voluntary muscles. They are composed of quadrangular and branched cells, which exhibit longitudinal as well as transverse striae. The nuclei are rounded and centrally placed within the fibre. They possess the power of inherent contractility. Moreover, there seems to be a free communication between all the cells, so that they can contract simultaneously.

IV. NERVOUS TISSUE.—**Nerve tissue** is composed of nerve cells and nerve fibres, with a special variety of connective tissue known as neuroglia.

Nerve cells are found in the grey matter of nerve centres or ganglia. These groups of nerve cells, known as ganglia (Gr. *ganglion*, a swelling), are found in the brain, on the spinal nerves, on the cranial nerves and along the course of the autonomic system. Nerve cells vary in size and shape. They all have a nucleus, often one or more nucleoli, and usually possess two processes at least. One is known as the **axon** (Gr. *axōn*, axis) and becomes the axis cylinder of a nerve fibre, the others (often branched) are called **dendrons**.

Nerve fibres are of two kinds : white myelinated or medullated, and grey amyelinated or non-medullated.

(a) The **white fibres** are an essential constituent of the cerebro-spinal nerves. They enter largely into the structure of the brain and cord. Large motor fibres to the voluntary muscles may have a diameter of 16μ , while smaller ones to involuntary muscles are about 3μ .

Each **white nerve fibre** is a minute filament constricted at intervals, consisting of a central thread (the *axis-cylinder* or *axon*), surrounded by a white sheath, the **myelin** or **medullary sheath**, and this again is surrounded by another fine membrane known as **neurolemma**, which is nucleated. The axon is really the continuation, as a long process, of the nerve cell to which it belongs.

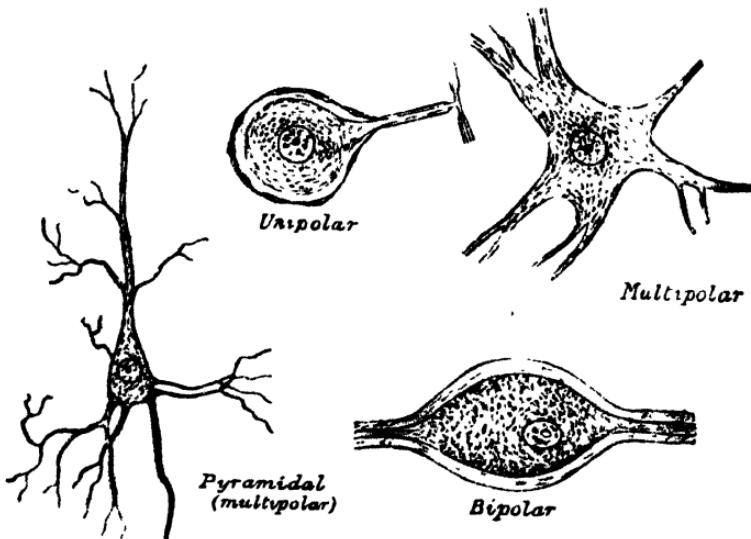


Fig. 200. **Varieties of Nerve Cells.**

The angular cells are motor, the rounded ones sensory.

(b) The **grey fibres** are found in the autonomic system as post-ganglionic fibres, and are characteristic of it.

They closely resemble the white fibres, but the sheath enclosing the axis-cylinder is wanting. It is doubtful whether there is a neurolemma or not. There is no known reason for this differentiation between white and grey fibres.

Each *anatomical nerve* is really a bundle of such fibres, passing to or from a nerve centre, generally bound together by a delicate sheath of connective tissue called the **perineurium**.

(Gr. *neuron*, a nerve; and *peri*, around). It may be easily distinguished in the body of an animal as having the appearance of white or cream-coloured threads.

The **neurone** is the histological or anatomical unit. It is composed of the dendrites, the nerve cell and the axon—the impulse passing in that order. Between the axon endings

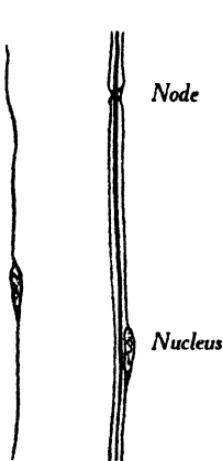


Fig. 201.—Nerve Fibres.

Left, a non-medullated nerve fibre; *right*, a medullated nerve fibre. The nerve cells are not shown.

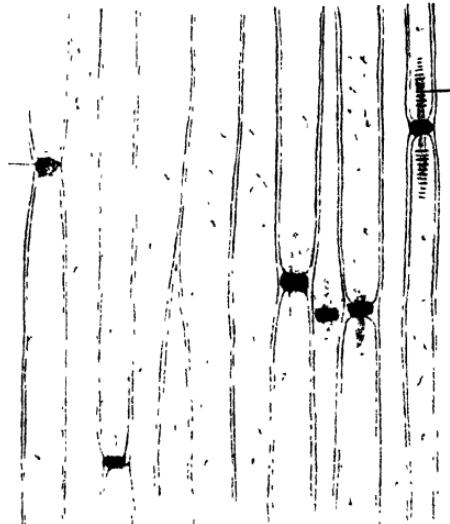


Fig. 202.—Myelinated Nerve Fibres Stained with Silver Nitrate.

The nodes (of Ranvier) are very well marked.

and the dendrites of the next neurone is a junctional region known as the **synapse**. It has important physiological properties, for here the nerve impulse sets free some chemical substance necessary for the transmission of the impulse to the next nerve cell, gland cell, or muscle fibre, as the case may be.

SUMMARY

I. EPITHELIUM—cellular tissue lining cavities, vessels and glands.

Structure—*Simple*—single layer of cells. *Stratified*—several layers.

Kinds—*Endothelium*—flat scale-like cells. Lines heart, blood-vessels, lymphatics, and serous cavities—one layer deep.

Glandular—globular or polygonal cells. Found largely in glands.

Columnar—single layer, lines stomach, intestines, ducts of glands.

Cubical—a variety of columnar cells in thyroid and kidney tubules.

Ciliated—air-passages and cavities of the brain.

Transitional—three to four layers deep. Lines urinary tract.

Neuro-epithelium—the receptor cells. Taste buds, rods and cones, olfactory cells, cells in crista, maculae, organ of Corti.

Functions—*Protection*—epidermis.

Secretion—crypts of Lieberkühn. *Sensation*—neuro-epithelium.

Motion (ciliary)—sex organs, trachea. *Absorption*—intestinal villi.

II. CONNECTIVE TISSUE—*for mechanical support of other tissues.*

Types—*Embryonic*—branched cells, umbilical cord, dental pulp.

Areolar—white and elastic fibres with wide meshes. Various sorts—adipose, lymphoid, reticular.

White fibrous tissue—protective. Dura mater, pericardium.

Yellow elastic tissue—ligaments, cartilages, arteries.

Cartilage and bone are special connective tissues.

Functions—to support and connect all other tissues.

Structure—cells, fibres, matrix, in varying degrees.

CARTILAGE (gristle)—tough, elastic, bluish-white and translucent.

a. *Hyaline*—articulating ends of bones, foetal bone, costal cartilage.

b. *White fibro*—glenoid cavity, acetabulum, small joints (wrist, ankle).

c. *Fibro elastic*—very flexible as in pinna, epiglottis.

BONE—by calcification of matrix either from membrane or cartilage.

a. *Ossification in membrane*—skull bones (frontal and parietal).

b. *Ossification in cartilage*—the long bones. Haversian system—canal, lacunæ, canaliculi, bone cells.

Periosteum—for nutrition of bone, and growth in width.

III. MUSCULAR TISSUE—*is structurally divided into three types:—*

1. Striated muscle (voluntary).

Composed of **bundles** or **fasciculi**. Latter composed of **fibres**, each surrounded by a sheath of *sarcolemma*. Size, $1'' \times \frac{1}{100}$ ".

Fibres made up of **fibrils**, which are striated transversely.

Many oval nuclei just under the sarcolemma.

2. Non-striated muscle (involuntary).

Found in the *muscular walls of the internal organs and vessels*.

Fibres composed of elongated cells with pointed ends, not marked transversely. Rod-shaped nucleus in centre of fibre.

3. Cardiac muscle—intermediate between the above two types.

Involuntary, yet faintly striped. Round nucleus, centrally placed.

Striated longitudinally and transversely.

Fibres composed of oblong and branched cells.

IV. NERVOUS TISSUE—the neurone is the histological unit :—

- a. The dendrons—branched processes bringing impulses to the cell.
- b. The nerve cell—of very variable size and shape.
Large nucleus, with one or more nucleoli.
- c. The axon—only one to each cell, carries impulses away from cell.
Coats—myelin sheath, and neurolemma.
- d. The synapse—junctional region between two neurones, concerned in the chemical transmission of the impulse.

EXAMINATION QUESTIONS

UNIVERSITY OF LONDON—SECOND M.B. EXAMINATIONS

1. Describe the minute structure of the mammary gland. What factors are responsible for the control of its activity? (1927)
2. What is meant by the term "basal metabolism"? How would you measure it in man? Under what conditions may it vary? (1927)
3. Discuss the factors involved in the digestion and absorption of fat. (1928)
4. Describe the minute structure of a renal glomerulus and tubule. What are the functions of the latter? (1928)
5. What are the chief causes of increased rate and depth of respiration? (1928)
6. Describe the minute structure of the ovary. What are the functions attributed to this organ? (1928)
7. Discuss the origin, function and fate of the red and of the white corpuscles of the blood. (1928)
8. What volume of urine is likely to be, or may be excreted by a man in an hour? What circumstances influence this volume, and how far are the facts accounted for by current theories of renal function? (1928)
9. What evidence would you produce to prove the circulation of the blood? (1928)
10. What do you know of the movements which take place in the small intestine? How have they been studied? (1928)
11. Describe the structures of the different kinds of corpuscles in human blood. What is the usual number of each variety in a cubic millimetre? Discuss the significance of physiological variations in these numbers. (1929)
12. Give an account of the functions of the skin, and the microscopical appearances of the structures on which they depend. (1929)
13. Under what circumstances does the output of the heart per minute vary? How are these variations brought about? (1929)
14. Under what physiological conditions do changes in the size of the pupil take place? Describe other changes in the eye that may be associated with them. (1929)
15. Describe the structure of the parathyroid. What is known as to its functions? (1929)
16. How does the human body react to a high external temperature? (1929)
17. Describe the minute structure of the capillary blood-vessels. What are their functions and how have these been studied? (1929)
18. Discuss the various conditions which influence the activity of the respiratory centre. (1929)

19. What do you mean by osmosis? Discuss its significance in physiological processes. (1929)
20. Give a brief account of the general functions of the autonomic nervous system (sympathetic and parasympathetic). (1929)
21. Describe the events of the cardiac cycle, and how they may be investigated. (1929)
22. Describe the minute structure of the liver. What information regarding the functions of the liver may be obtained from a study of its histology? (1930)
23. Describe and explain the effects of asphyxia on the circulation. (1930)
24. Describe the minute structure and functions of the iris. Under what conditions does the size of the pupil vary? (1930)
25. What is the origin, function and fate of the fat in the body? (1930)
26. What do you understand by the terms diffusion, filtration and dialysis? What is the significance of these processes in physiological activities? (1930)
27. Describe with the aid of diagrams the formation of retinal images in (a) the resting eye, and (b) the eye accommodated for a near object. (1930)
28. What is the evidence for the functions ascribed to the pituitary body? (1930)
29. Give an account of the means whereby the arterial blood pressure is regulated. (1931)
30. Discuss the factors concerned in the maintenance of the blood pressure. (1932)
31. By what means does a warm-blooded animal maintain its temperature under changing conditions of the environment? (1932)
32. Describe the origin, functions and fate of the constituents of the bile. (1934)
33. Describe the structure and functions of the spleen. (1934)

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